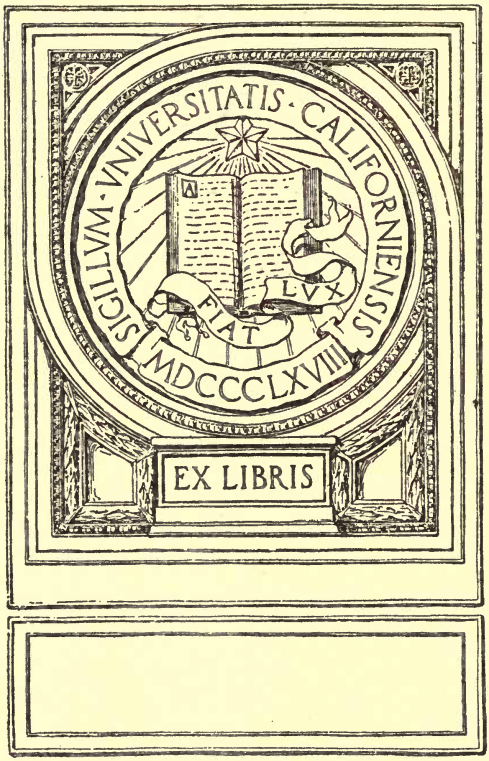
CHEMICAL ENGINEERING

J. W. HINCHLEY

UC-NRLF
$B 276 595

YB 15491


SIGILLVM · VNIVERSITATIS · CALIFORNIENSIS
FIAT
LVX
MDCCCLXVIII
EX LIBRIS

CHEMICAL ENGINEERING. NOTES ON GRINDING, SIFTING, SEPARATING AND TRANSPORTING SOLIDS.

Text-books of Chemical Research and Engineering.

Edited by W. P. DREAPER, F.I.C.

PHYSICS AND CHEMISTRY OF COLLOIDS.

By EMIL HATSCHEK. With 14 Illustrations. 2s. 6d. Net.

NOTES ON CHEMICAL RESEARCH.

By W. P. DREAPER, F.I.C. 2s. 6d. Net.

MOLECULAR PHYSICS.

By J. A. CROWTHER, M.A. With 29 Illustrations. 3s. 6d. Net.

TEXT-BOOKS OF CHEMICAL RESEARCH AND ENGINEERING.

CHEMICAL ENGINEERING. NOTES ON GRINDING, SIFTING, SEPARATING AND TRANSPORTING SOLIDS.

BY

J. W. HINCHLEY, A.R.S.M., WH.SC.

CONSULTING CHEMICAL ENGINEER, FELLOW OF THE CHEMICAL SOCIETY, MEMBER OF THE SOCIETY OF CHEMICAL INDUSTRY AND OF THE FARADAY SOCIETY, FORMERLY TECHNICAL HEAD OF THE SIAMESE MINT.

LECTURER ON CHEMICAL ENGINEERING AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON, AND AT THE BATTERSEA POLYTECHNIC.

REPRINTED FROM "THE CHEMICAL WORLD."

With 70 Illustrations.

LONDON

J. & A. CHURCHILL

7 GREAT MARLBOROUGH STREET

1914

TP155
.H5

PREFACE.

THIS book is a slightly enlarged reprint of a series of articles which appeared in *The Chemical World*.

It is an attempt to provide a concise and practical outline of a subject of great scope, for the use of students in chemical engineering and allied subjects.

J. W. HINCHLEY.

321771

CONTENTS.

PAGE

CHAPTER I.—SIZE-REDUCTION OF SOLID MATERIALS 1

Crushing. The laws of crushing. Coarse crushing machines. Rock-breakers. Medium crushing machines. Crushing rolls. Fine crushing machines. Centrifugal rolls. Edge runner mill. Griffin, Bradley and Huntingdon mills. Fuller mill. Ball mill. Tube mill.

CHAPTER II.—SIZE-REDUCTION OF SOLID MATERIALS (*continued*) 22

Grinding machines. Roller jaw mill. Differential roller mill. Millstone mill. Eccentric mill. End runner mill. Triple roller mill. Setting and truing roller mills. Disintegrating machines. Carr's disintegrator. Carter's disintegrator. Perplex disintegrator. Stamp mill.

CHAPTER III.—SIFTING 40

Fixed screen sifters. Trough sifter. Cylindrical sifter. Gyrating sifter. Vibrating sifter. Newago screen. Cylindrical trommels. Sifting reel. Hexagonal reel. Reel with paddle elevators. Reel with beaters. Opening factor. Wire cloth. Twilled wire cloth. Piano wire screens. Sifting action. Calculations relating to sifting.

CHAPTER IV.—SIZE SEPARATION BY FLUID MEDIA 58

Jigs. Settling troughs. Gee's centrifugal separator. Elutriating plant. Freygang's elutriator. Dry separators. Cylindrical separator. Motion of particles in separators.

PAGE

CHAPTER V.—SEPARATION OF SOLIDS BY MAGNETIC METHODS 67

Lifting and deflecting machines. Wetherill's separators. Ball-Norton separator. Magnetic drum. Monarch separator. International separator. Magnetic shoot. Separation of solids by electro-static methods.

CHAPTER VI.—MIXING OPERATIONS 75

Vicker's mixer. Sun and planet mixer. Pug mill. Double paddle. Niagara paddle. Conical paddle. Gardner's mixer. Universal mixer. Butter worker. Plodding machines. Consolidating press. Mixing rolls.

CHAPTER VII.—THE TRANSPORT OF SOLID MATERIALS 87

Wheel barrow. Trucks. Runways. Screw conveyor. Coefficients of internal friction of materials. Scraper conveyors. Band conveyors. Heavy band conveyors. Vibrating trough conveyor. Elevators.

CHEMICAL ENGINEERING.

Notes on Grinding, Sifting, Separating and Transporting Solid Materials.

CHAPTER I.

Size Reduction of Solid Materials.

Practically all solid raw materials and many finished products of the chemical manufacturer must be reduced to some degree of uniformity in size, determined ultimately by economic considerations. Many raw materials are reduced in the first instance by the hand hammer, either because the careful sorting which may be necessary to prevent subsequent loss can readily be given by this means, or the production of "smalls" can only be adequately avoided by hand work, or the quantity to be treated is too small to pay for the installation of special plant. One man can usually reduce hourly from one quarter to one half of a ton of large lumps to pieces passing through a $2\frac{1}{2}$ in. diameter ring, and the cost may be taken as twice that of machine work, viz., 8*d.* to 1s. 4*d.* per ton, according to the hardness of the material.

In all chemical operations, whether coarse or fine reduction is necessary, there are economic limits of size which give the maximum return. These limits for economic efficiency do not necessarily coincide with those giving the greatest chemical efficiency. In other words, the lowest "cost of production" is

not always obtained by conditions which give the most efficient reactions.

All size-reduction machines operate in one or more of three distinct ways, by crushing, by grinding, or by impact. Rock-breakers and crushing-rolls reduce the material mainly by simple compression—*crushing;* in mill-stone mills, roller and other paint mills, the particles are mainly subjected to shearing stresses—*grinding;* and the disintegrator breaks up the material by means of blows on the unsupported grains—*disintegrating.*

In determining the size, capacity and power required for the size-reduction of different materials by different machines, the factors which enter into the calculation are so variable that it is necessary to allow a considerable margin. The compressive strength of the material to be crushed commonly varies from one half to twice its average value, and materials of the same character and composition from different localities may vary from one-eighth to four times the average value. It must also be borne in mind that the compressive strength is apparently greater in small than in large pieces of material.

Since the real work of crushing must be proportional to the amount of new surface produced, this work will vary directly with the compressive strength of the material and inversely with its density. An additional factor which is difficult to estimate enters into the problem, viz., the average amount of deformation which takes place before fracture occurs. Other properties of materials, also, complicate the problem to such a degree that judgment and experience often become a safer guide than deductions from theoretical reasoning; such properties as hardness, tenacity, greasiness, and structure when exhibited in considerable degree, usually necessitate practical tests on a semi-factory scale before a sound judgment may be reached.

It is convenient, however, in making calculations on crushing and grinding to take a material as a standard and compare other materials with it. Limestone having a compressive strength of 10,000 lbs. per sq. in. is a very satisfactory standard. Simple factors may then enable one to estimate with practical closeness for the provision of grinding plant. Such a factor for chalk would range from ·1 to ·4 for compressive strength, for limestones; dolomites and sandstones, from ·4 to 3; for granites, quartzites, etc., from ·5 to 3; and for pyrites from ·1 to 4.

The efficiency of crushing and grinding plant is always comparatively low on account of the power lost both in the machine and in the material. Some of the lost power appears in the material ground from the wearing parts of the machine; much is evident as heat in the machine, the material and the air; some is lost by plastic and unrecovered elastic deformation of the material, and the useless production of dust; and some, also, is evident as sound, for noisy machinery is always associated with inefficiency.

The statement that the amount of new surface produced by crushing or grinding is a measure of the real work performed by a size-reduction machine, enables one to calculate outputs provided that we have some notion of the efficiency of the machine under consideration. Factory results show that the amount of work done compared with the area of the fractured surface is constant for coarse sizes, but with fine grinding, the amount of new surface produced is greater than indicated by the above generalisation. This difference is, no doubt, largely due to the effect of the previous coarse crushing in deforming the particles and producing incipient fractures and thus facilitating the finer reduction.

This rule may be stated thus :—

H.P. required per unit weight per hour =

$$A\left(\frac{1}{d_2}-\frac{1}{d_1}\right),$$

where d_1 is the average diameter of the particles fed to the machine, d_2 the average size of the ground product and A is a constant for the material. The value of A may be calculated by reducing a sifted quantity

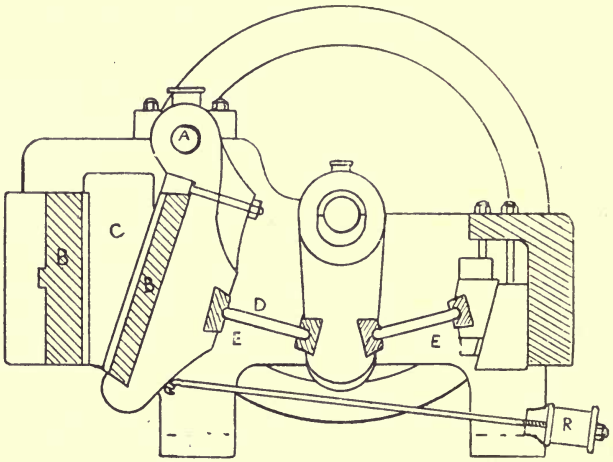


FIG. 1.—BLAKE CRUSHER.

of the material, measuring the power and sizing the finished product. If the product is very variable in size then $\frac{1}{d_2}=\frac{a}{d_3}+\frac{b}{d_4}+\frac{c}{d_5}$ where a, b, c are factors showing the amount of each diameter present in unit weight of the product, and d_3, d_4, d_5, are the respective diameters. The machine in which the test is made should be worked at or have the same efficiency as that to be used, or a correction must be introduced to cover this error.

Coarse Crushing Machines: Rockbreakers.

This class of machines depend upon the lumps being crushed between a fixed surface and a surface which approaches and then recedes from the fixed surface. The simplest type, usually called a "jaw-breaker," in which the surfaces are plane, has a moving jaw which swings on horizontal bearings. The gyrating type in which the surfaces are circular has a conical head mounted upon a gyrating spindle so that when one part of the surface is approaching and crushing the opposite part is receding and allow-

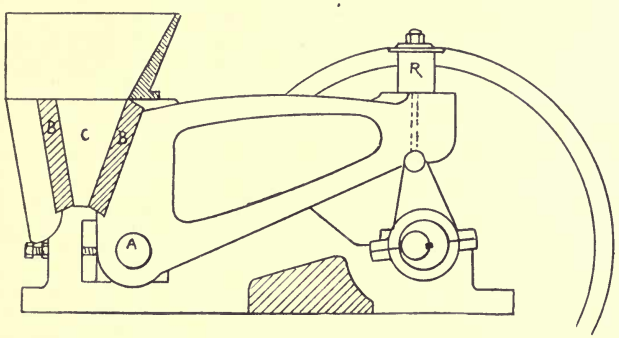


FIG. 2.—DODGE CRUSHER.

ing the product to fall for new material to take its place. Such machines have the advantages of large output and continuous action.

In the jaw-breaker type, the hinge A of the jaw may be near the mouth of the machine as in the Blake Crusher (Fig. 1), near the outlet as in the Dodge Crusher (Fig. 2), or the moving jaw may be actuated by levers in such a manner as to produce a rolling action as in the Samson Crusher (Fig. 3) and other makes.

The advantage of one class of machine over another is not very pronounced provided that the

design is strong and the quality of workmanship good. The action of the Blake Crusher is excellent, but the product is not so regular in size as that from the Dodge Crusher. On the other hand the Dodge Crusher is noisy and must be fed evenly or choking

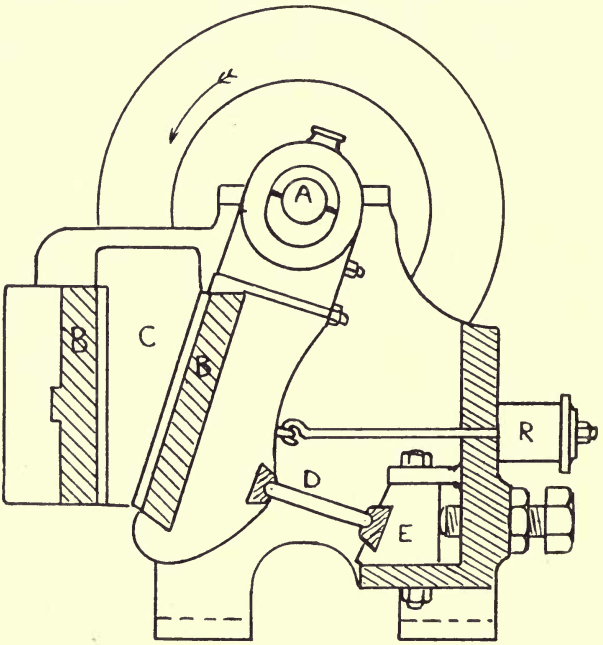


FIG. 3.—SAMSON CRUSHER.

takes place with the production of much fine material. The stresses in the Dodge Crusher are higher than in the Blake and the mechanical efficiency is often lower in consequence. The output from the gyrating type is very large indeed but the product is more irregular than that from the Blake.

In the jaw-breaker type the movement of the jaw

varies from $\frac{1}{8}$ in. at the point of smallest movement to $\frac{1}{2}$ in. at the point of greatest movement, and the speed may be from 250 to 300 revolutions per minute. The performance of different machines may be approximately compared by the area at the mouth. The angle between the jaws must be considerably less than the angle of friction for the material, or the lumps to be crushed would jump out, and is usually about 18 degrees. The adjustment for the size of product is made by moving the lever bearings or jaw bearings by means of screws and wedges. As a rule 1 cwt. of standard material may be crushed per hour from 4-in. to 2-in. cubes per square inch of mouth opening, *i.e.*,

Output in tons per hour = ·05 A, where A is the area of the mouth in square inches. The horse-power required for the work will be ·1 A and the price of standard machines is approximately = £ (·8 A+30).

The frames of these machines must be absolutely rigid, and there is little doubt that cast-iron, from the economic and utility point of view, is the most satisfactory. Cast-steel or built-up frames are often recommended, but their use should be restricted to places where transport and erection are costly and difficult. The design should be as simple as possible, for additional levers mean extra strains and more energy loss. The desire to obtain a good hammer action is often responsible for complication without any balance of advantage. The mouth and jaws should be machined so that new jaw plates, etc., can be fitted without trouble, and provision should be made so that wear can be equalised either by turning the jaw plates upside down or by making them in parts. The jaw plates B and side plates C are usually made of hard steel or chilled cast-iron. Manganese steel, when of good quality, is undoubtedly the best material for wear and tear, but in chemical work it is doubtful whether it shows any

economic advantage over chilled cast-iron. The working faces are V-grooved vertically to reduce the work of crushing by applying the forces at definite points and to diminish the amount of " smalls " by avoiding grinding action.

The jaw and other plates are usually fixed by wedge-headed bolts and bedded into place by means of molten zinc or white metal. A better way of bedding the jaw plates is to provide recesses at their backs to carry plugs of white metal of some standard form, which squeeze and finally equalise the pressure all over the jaws.

Large bearing areas on the bearings and provision for lubrication which has little risk of admitting grit to the bearings are points of great importance. With best workmanship gun-metal or phosphor bronze bearings are better than any other, but where rough repairing is likely to be met with white metal faces to the bearings are desirable.

Ease of operation also depends to a large extent on the careful fitting of the toggles D and joints E. The fly-wheel power should be sufficient to ensure a good hammer action, *i.e.*, steady running. Some safety arrangement must be provided so that when a piece of metal falls between the jaws a replaceable breaking piece, key, pin, etc., gives way before any other damage is done.

A good foundation for such machines is a distinct advantage, but is not essential to good working.

The life of such machines may be taken as ten years, and the cost of renewal of jaw plates at from 1*d.* to 2*d.* per ton of material crushed.

Medium Crushing Machines; Crushing Rolls.

Rock-breakers are not very efficient machines for materials smaller in size than 1 in. (the Samson machine, however, reduces efficiently to $\frac{1}{2}$ in. size),

and medium size-reduction is usually made by means of crushing rolls. They consist (Fig. 4) of two cylinders which, by revolving towards each other, draw and crush lumps of material between them. Such rolls must run at, practically, the same peripheral speed or grinding action with excessive dust production occurs.

Crushing rolls may be worked either wet or dry, and are most efficient for reducing down to ·015 in.

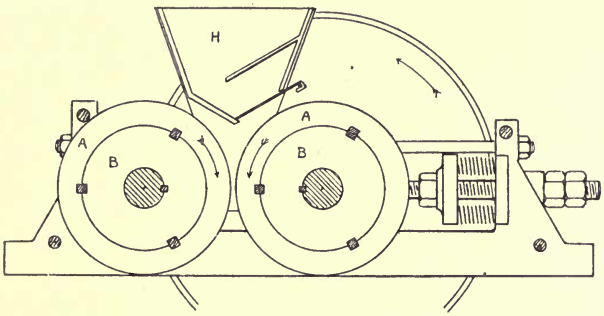


Fig. 4.—Crushing Rolls.

For finer reduction than this, ball mills, tube mills, and disintegrators are more suitable.

The peripheral speed of crushing rolls varies in practice from 30 to 1,000 ft. or more per minute, and although the size and character of the material has a determining effect on these speeds, the mechanical construction has a greater.

High speed rolls are only possible when each roll is belt-driven separately. Where the rolls are geared together mechanical difficulties compel a reduction of speed and a low efficiency is obtained.

An estimate of the most suitable speed for rolls for a given material is :—

$$S = 1{,}000 - 300 \log,$$

where S is the peripheral speed in feet per minute, and d is the diameter of the particles of fed material in $\frac{1}{100}$ of an inch (the logarithm being to the base 10).

It will be obvious that there is some relation between the maximum size of particle and the size of the rolls so that slip shall not occur. The considerations which apply to the angle between the jaws of jaw-breakers apply here. As a rule the rolls are set to a distance apart equal to the size of the finished product, and held in position by means of springs which give way when hard foreign substances are accidentally fed.

The angle between the tangents at the points which the largest fed particle touches the rolls is called the angle of nip and is usually for ordinary materials 30° to 32°. Taking the best angle of nip as 32° then

$$\text{Diameter of rolls in inches} = 25\ (\cdot 96\ d_1 - a),$$

where d_1 is the size of the fed particles in inches and a the distance in inches between the rolls.

The actual output of rolls is capable of approximate estimation. If f be the ratio of the width between the rolls to the diameter of the particles of charged material, *i.e.*, $f = \frac{a}{d_1}$, A, the area of the opening in square feet and S the peripheral speed of the rolls in feet per minute then—

Volume of material passed in cubic feet per minute

$$= \text{AS}\ (\cdot 6\ f + \cdot 15).$$

Knowing the weight of a cubic foot of the material, it is a simple matter from this to determine the weight per hour which may be expected as the output for the machine.

Rolls for crushing, in common use, vary in diameter from 9 ins. to $3\frac{1}{2}$ ft. With a given diameter the width of the rolls is determined by several

practical considerations. Narrow rolls are more easily kept in order, and produce smaller variations of stress in the frames, and consequently less frictional losses ; in addition, they can be run at a higher speed, but one must bear in mind that after exceeding the economic speed no advantage is gained. Taking all the factors into consideration, a width of 10 ins. seems to be satisfactory for most conditions when crushing mineral substances.

Although with large rolls the output and range of reduction is greater than with small rolls, the use of two pairs of small rolls above each other in the same frame is generally more economical, both in first cost and in use, than performing the reduction in one operation with large rolls. In practice, there appears to be no economic advantage in using rolls over 24 ins. diameter.

While true crushing conditions are obtained by running both rolls at the same speed, better conditions of wear are secured by running one roll 1% faster than the other; the faster roll is also best driven by means of a smaller pulley and belt, so that slip may occur rather than excessive grinding of the roll shell.

Although the economic speed given approximately by the formula previously mentioned ($S = 1{,}000 - 300 \log d$) is the best, speeds much lower than this are usually found in practice. It may be mentioned that slow running always increases the proportion of fines and dust. Such slow speeds are usually due to faulty mechanical arrangements, defective foundations, or lack of interest in obtaining the highest efficiency.

Rolls are usually made in two parts, viz., a roll centre and a roll shell. The roll shells are trued as they wear and replaced when worn out. They are often bored taper and held on the centre by means of draw bolts ; another, but less satisfactory

method of fixing them to the centre consists in using wooden wedges, internal key-like projections on the shell fitting into key-ways in the centre ; in this case the shells are not bored ; occasionally shells are built up in sections, each section being held by two bolts. Chilled cast iron or cast steel are the most efficient materials for shells, although manganese steel or steel forgings are more durable.

The simplest means of truing shells consists in traversing an emery wheel across them every other day or when the amount of uneven wear becomes troublesome. A simple fitting can generally be provided on the roll housings for this purpose.

The sides of the hopper are best placed outside the edges of the rolls, so that an even feed causes the whole faces of the rolls to wear evenly. In any case an even feeding arrangement is most essential for the best results.

The springs on the bearings of the rolls should only come into play on the journals of the rolls when accidentally large material or metal enters the mill. If the springs are continually in action, the power for crushing is increased, but the wear and tear of the journals produce serious items of renewals.

When even crushing to a definite size is desirable with a minimum production of smalls, transverse grooves are provided in the rolls to reduce grinding action to a minimum. Longitudinal grooves may also be cut so as to form pyramidal teeth. Materials such as bones, coke, ice, resin, crystals, etc., may be reduced in such mills with a minimum production of dust.

Such rolls are often mounted vertically, sometimes with five or six in one housing, for the crushing of seeds, canes, etc.

With standard limestone the amount of material crushed from $1\frac{1}{4}$ ins. diameter to $\frac{1}{4}$ in. diameter is approximately $\frac{1}{2}$ ton per h.p.-hour. With such a

material, when running 24-in. rolls at a peripheral speed of from 200 to 250 ft. per minute, the horse-power required would be ·025 diameter of rolls multiplied by their width (both in inches).

Fine Crushing Machines.

Some of the most successful fine size-reduction machines depend mainly on the crushing principle. Among the best are centrifugal rolls (Fig. 5). These rolls differ from ordinary rolls by the provision of weights and springs between the roll centres and

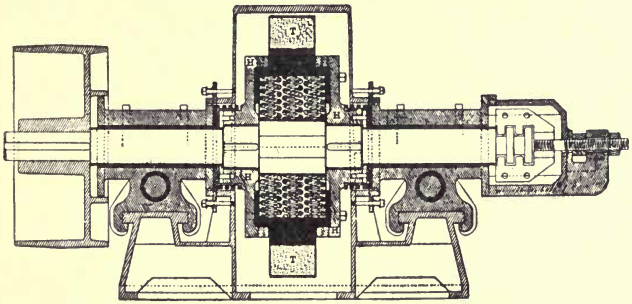


Fig. 5.—Centrifugal Rolls.

the shell with provision for radial movement only of the shells with respect to their centres. Such rolls are provided with rigid but adjustable bearings, and the crushing surfaces are set closely together. Unlike ordinary crushing rolls which have an economic speed, centrifugal rolls give an output in proportion to their speed, the limit of output being mainly a question of wear. Both rolls are usually driven by the same belt, and in spite of the enormous forces involved, on account of their easy action and the absence of shock, comparatively small pulleys are required. The speed must be

adjusted to the character of the material to give the minimum cost of working.

There are many modifications of rolls for fine crushing in which an internal roll or ring is used. In the Sturtevant ring-roll mill the ring is rotated vertically, and a series of stationary convex rollers are pressed by springs against the internal concave grinding surface of the ring. The grinding ring, which is renewable, rotates truly at a peripheral speed of about 650 ft. per minute, the pressure between each roll and ring being about 10 tons. The material is delivered on the concave face of the ring and remains there by centripetal force until crushed off both sides by the action of the convex rolls. On account of the freedom from grinding action, the wear of the rolls and ring is remarkably small, but the product must be sifted and the coarse material returned, entailing another operation.

In the Griffin (1 roll), Bradley (3 roll) and Huntingdon (4 roll) mills, the ring is stationary, and the spindles carrying the roll or rolls are rotated so that the working pressure is obtained entirely by centripetal force. On this account their action is not so smooth as that of the ring-roll mill, and it is very much affected by alterations in speed. In such mills, if particular attention is paid to maintaining well finished, well lubricated, and grit-proof bearings with true wearing parts, the cost of reduction may be kept very low, but they do not give satisfaction for the very finest class of size-reduction without first-class supervision.

A common type of crushing mill, of general application, is the edge runner mill (Fig. 6), of which the ordinary mortar mill is a common type. It consists of one, two or three heavy rolls of cast iron or stone which roll round a pan containing the materials to be crushed. In some machines the pan is driven, in others the axles carrying the rolls,

scrapers being fitted in both cases to move the materials into the path of the rolls. Such mills are usually worked discontinuously, the materials being charged and discharged at convenient intervals. When working continuously steel grids are provided through which the material passes as it becomes reduced. When used for crushing clay,

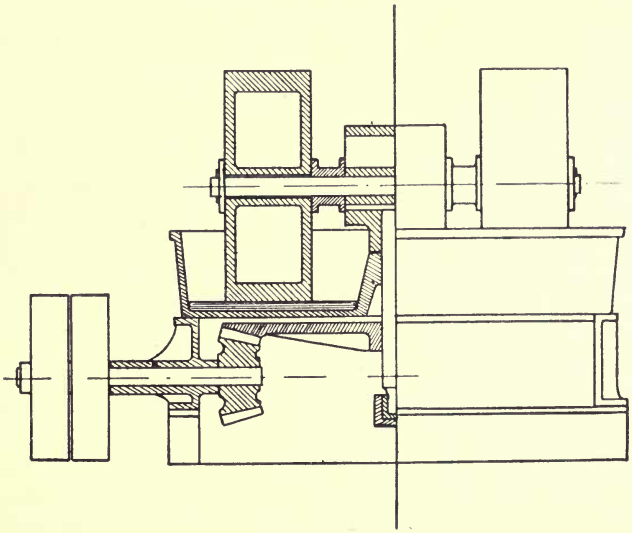


FIG. 6.—EDGE RUNNER MILL.

holes of from $\frac{1}{8}$-in. to $\frac{1}{4}$ in. are provided through which the material is forced. Where heating must be avoided, as in gunpowder work, the rolls are always supported out of contact with the pan so that crushing only takes place when the pan is covered to a definite depth with material. Since the crushing pressure is limited by the weight of the rolls, edge runner mills are not suitable for very hard materials unless the fed material is small in size. A high-

class mill with two rolls, 4-ft. diameter and 8-in. face, each weighing 1 ton, driven at 40 revolutions per

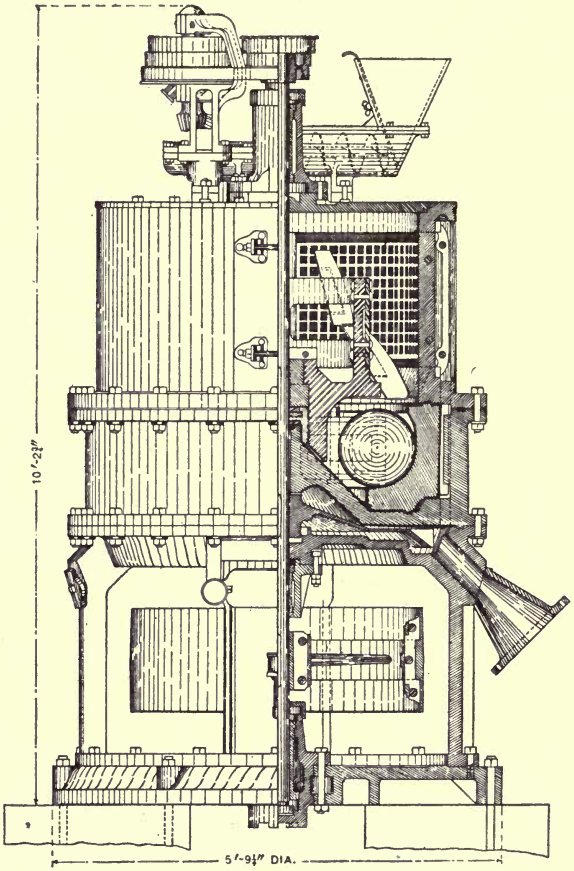


FIG. 7.—FULLER MILL.

minute, will be capable of crushing 4 tons of standard limestone per hour from $\frac{1}{4}$ in. size to ·012 in.; an

ordinary mill under ordinary conditions has about a quarter of this capacity.

Although a considerable amount of grinding action takes place in the edge runner mill, it is not suitable for very fine reduction, but is very popular where the material may be left granular. Sometimes the rolls are grooved for dealing with special materials. For reducing seeds, clay, chalk, roasted products, they are slow but satisfactory.

A large number of fine crushing mills are made in which one or more balls are made to roll in a horizontal ball race or grinding ring. Some of these mills are capable of producing at one operation a product equal in fineness to standard cement. One of the best is the Fuller Mill (Fig. 7). In this mill a number of balls are rapidly driven round the crushing ring with a speed at its surface of about 1,800 ft. per minute. The finely crushed product is raised as a cloud, and by the agitation of the air is projected through the screens seen in the upper part of the mill. Any coarse material falls back again to be re-crushed.

For the reduction in such mills of 1 ton per hour of standard limestone from $\frac{1}{4}$ in. size to the fineness of standard cement (not more than 18% retained on a 180-mesh sieve, and not more than 3% on a 76-mesh sieve) 10 to 12 h.p. is required.

In recent years ball mills and tube mills have become very popular for fine reduction on account of their simplicity of construction, ease of working, absence of delicate parts, freedom from breakdown, and low cost of upkeep.

Such mills consist of a rotating chamber containing balls which crush the material as they fall or roll in its interior. The product is very fine, fairly even, and may be produced so as to need no sifting. A simple type of such mills consists of a stoneware or biscuit porcelain jar which is mounted

in a frame for rotation about its axis of symmetry. The jar is half filled with flint pebbles or porcelain balls 2 ins. diameter, and sufficient material to more than fill the voids between the balls by about 10%. The jar is closed and rotated on its axis at a peripheral speed of about 160 ft. per minute for a period long enough to give the required reduction. For reducing and mixing small quantities of chemical products such mills are most useful, and since the cost of jars is small, cleaning up and its resultant loss may be avoided by stocking one jar for each product. Ovoid pebbles appear to give better results than round ones, which would seem to show that the grinding is more important than the crushing effect.

For large outputs steel drums lined with porcelain bricks or quartzite blocks are used with flint pebbles of 3 to 5 ins. diameter. For reducing lumps to dry powders, and at the same time associating the powder with small quantities of liquid, these mills are most satisfactory, and are used for disinfecting powders, tooth-powders and materials for plastic compositions, etc.

For large outputs and continuous working the ball mill with screens or the tube mill are efficient.

In the ball mill with screens (Fig. 8) the drum is formed by a series of hard steel grinding plates arranged in steps as shown. As the material is crushed it falls through the perforations in these plates and is sifted by the circular check sieve and finally by the outer fine sieves. The material rejected by these screens is lifted and falls through the gaps between adjacent grinding plates and into the crushing space again. Such a mill usually gives a little over half the output of the Fuller Mill per h.p. per hour. As a rule this type of mill is only used for the preliminary grinding, its product being delivered to a tube mill for further reduction.

The tube mill is the most popular mill for fine

crushing, and consists of a rotating steel tube, those in common use being from 10 to 30 ft. long and 3 to 6 ft. in diameter, lined with cast steel, chilled cast iron plates or quartzite blocks and charged with flint pebbles or steel balls of from 3 to 5 ins. diameter.

The material, which has already been reduced to

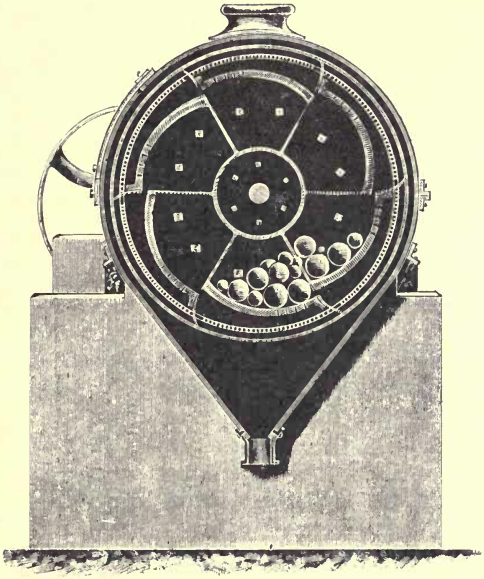


FIG. 8.—BALL MILL.

at least $\frac{3}{4}$ in. size, is fed in through one of the hollow trunnions and is delivered at the opposite trunnion. The rate of feed determines the rate of delivery and the amount of crushing accomplished. The feed is generally arranged with a worm, but there are other devices for both feed and delivery which are doubtful improvements on the simple type.

The amount of power required is rather great if

the whole of the reduction is accomplished in one operation, and on this account it is becoming common to pass the product through an air separator and return the coarse material for further reduction.

Davidsen's rule for the amount of pebbles in a tube mill is W = 44M lbs., where M is the volume of the tube in cubic feet. The number of revolutions at which the tube should be driven $= \frac{200}{\sqrt{D}}$ where D is the diameter in inches; and the horse-power required = ·15 M. If the charge of flint pebbles is greater or less than that given by Davidsen, then the power required will be greater or less in proportion. As little as 1½% moisture is usually sufficient to upset the good working of all these fine crushing machines. On the other hand, such machines work excellently with a considerable amount of water (50% or more).

Reduction in size by means of tube mills may take place in three distinct ways, and the extent to which any method predominates is determined by the conditions. The balls may crush the material by rolling upon the lining and on each other; by impact, through the projection of the balls after being lifted by the rotation of the mill; and by grinding, through the sliding of the balls on the lining and on each other. In dry working with a smooth lining the work done by the mill is very much reduced, but as soon as the surface of the lining becomes roughened the balls are lifted and the rate of working immediately improves. In dry grinding, impact action is therefore important, but when grinding wet the intensity of the blows must be much reduced by the water, and it would appear that crushing by rolling would be more prominent. But in wet grinding ovoid pebbles usually produce distinctly better reduction and a higher efficiency, although in dry working the reverse statement is

true. For dry reduction, therefore, the tube mill should be treated as a crushing machine, and for wet reduction as a grinding mill. The size, shape and density of the balls, the volume they occupy, and the speed of rotation all have a distinct effect on the proportions in which the different actions take place. A perforated plate at the discharge end of the machine allows the pebbles to be discharged when too small for effective work. The noise which is produced by the action of the mill is the best working indication of its action. The best speed for dry reduction is usually about 10% higher than that given by Davidsen's rule and that which is satisfactory for wet working. The volume occupied by the pebbles should be from ·50 to ·55 times that of the tube, fresh pebbles being added through the manhole from time to time as the old pebbles are reduced in size and discharged from the machine. The volume of pebbles may, with advantage, be greater for wet than for dry reduction, and also when the very finest grinding is required ; for rough work, the volume of pebbles may be somewhat less than given by the rule.

The shells of these mills are usually built up of steel plates, $\frac{3}{8}$ in. to $\frac{5}{8}$ in. thick, and in perhaps the most efficient size, viz., 15 to 20 ft. by 4 ft. diameter, the plates would be $\frac{1}{2}$ in. thick. The shells are either rotated on trunnions at each end, through which the feed and discharge takes place, or circular rings may be provided to run upon rollers ; the latter method is the most economical of power, unless anti-friction devices are provided on the trunnions.

The discharge in some mills is made from perforations in the shell at the periphery, but this method is not so satisfactory as axial discharge.

CHAPTER II.

Size-Reduction of Solid Materials—(*continued*).

Grinding Machines.

Size-reduction machines which act mainly by grinding, or by subjecting the material to shearing stresses, do not offer so many variations of type as crushing machines, but an additional factor often appears—the adhesion of the material to the grinding surface.

Coarse Grinding Machines.

These machines consist of a toothed or grooved surface, which moves past a similar fixed surface. The surfaces may be cones, discs or cylinders, or combinations of these forms. For coarse work alone, except when treating soft materials and grain, such machines are not efficient in power, but, owing to the production of a uniform small size, are extremely useful in many classes of work. A conical machine for heavy work (Fig. 9) is made, capable of reducing rock at one operation to $\frac{1}{8}$ in. size at the rate of over 15 tons per hour. Such machines are made in all sizes down to the ordinary domestic coffee or pepper mill. For the enormous range of reduction these machines are remarkably efficient, but they are not suitable for quartz or materials of greater hardness. The wearing surfaces, which are renewable of necessity, are of chilled cast-iron, and can be rapidly replaced. On account

of their low first cost, ease of management, and range of usefulness, these mills are popular for limestone, graphite, steatite, gypsum, etc. In such machines one-horse power per hour is capable of reducing 10 cwts. of standard limestone to $\frac{3}{16}$ in. size.

Disc machines (Fig. 10) for medium grinding are

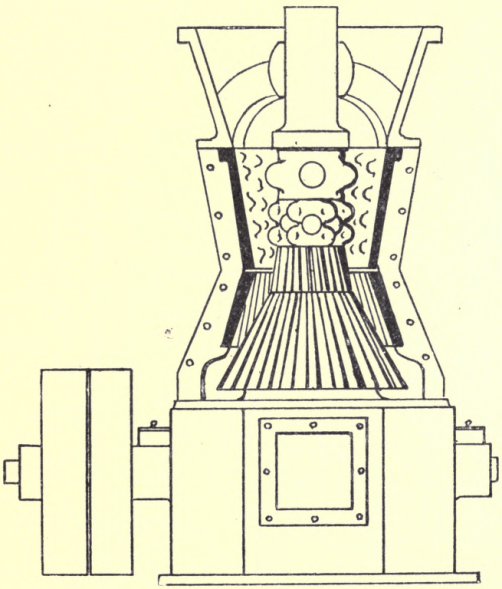


FIG. 9.—CONICAL GRINDING MILL.

in common use for comparatively soft materials—grain, charcoal, cake, etc.

Roller machines of similar character, in which a toothed or grooved roller forces the material past a fixed jaw (Fig. 11), are commonly used for breaking down clay and similar compact materials.

Modifications of these machines are obtained by providing a differential movement to both surfaces,

with the advantages of more even wear and definite feed. Conical machines modified in this way are well known for kibbling, or reducing to meal, cereals, etc.

The disc mill is usually modified by placing one

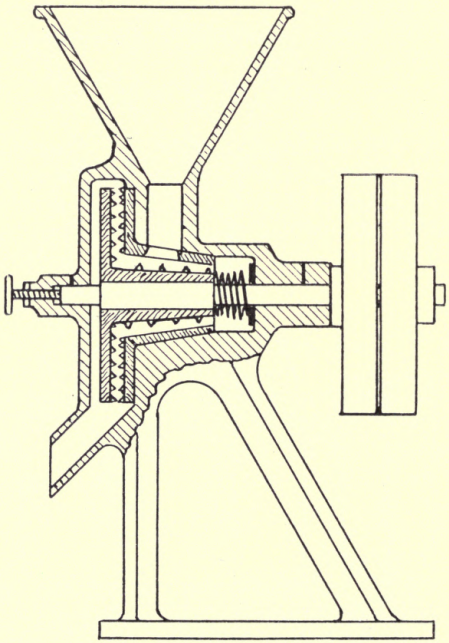


FIG. 10.—DISC MILL.

of the discs out of centre and allowing it to be rotated by the grinding action between the two. By this means the material travels radially across the concentric grooves or teeth in the discs and is broken up by simple shearing actions, and the surface friction of the fixed disc type is avoided.

Roller mills are similarly modified by substituting a rotating toothed roller for the fixed jaw (Fig. 12),

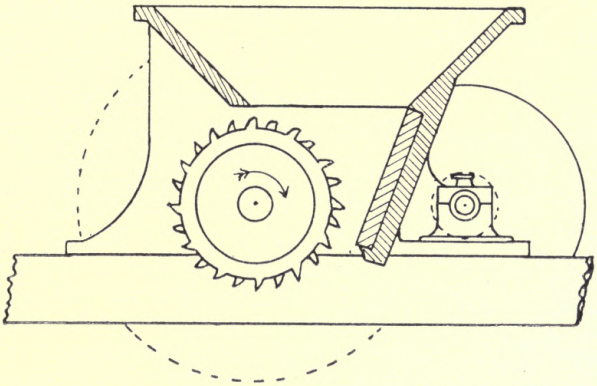


FIG. 11.—ROLLER JAW MILL.

and gearing the two rollers together in a velocity ratio of about 3 : 1. By reciprocating one of the

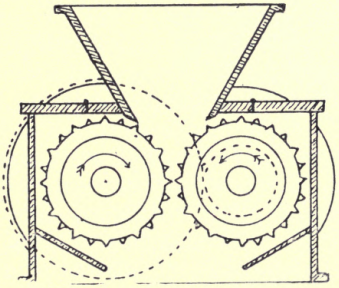


FIG. 12.—ROLLER MILL.

rollers longitudinally a further useful modification is obtained in that the wear on the rollers is equalised to some extent.

In all coarse grinding machines adjustments are

provided so that the toothed surfaces cannot come into actual contact, while, in fine grinding machines, it is common to allow this to take place, the pressure between the grinding surfaces being adjusted rather than their distance apart.

Fine Grinding Machines.

All types of coarse grinding machines are also designed for fine grinding by the provision of suitable grinding surfaces and arrangements for

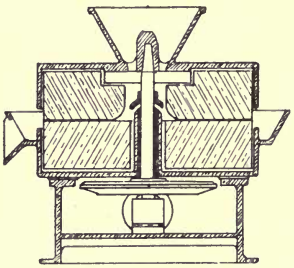


FIG. 13.—MILLSTONE MILL.

their adjustment. The workmanship must, however, be of the highest class for satisfactory results.

Most of the fine grinding in the chemical and spice trade is done on millstone mills (Fig. 13). The grinding surfaces are horizontal discs or millstones, one of which, either the upper or the lower, is fixed, and the other rotates concentric with it. The material is fed through a central hole in the upper stone from 8 ins. to 10 ins. diameter. The stones are usually French buhr, built up and supported on a backing of suitable cement or plaster. Other stones, such as granite, marble or stoneware, are used for grinding special materials. Such mills, although slow, are excellent for general work, but for the finest grinding are difficult to keep in perfect

order. Furrows, about $\frac{1}{2}$ in. deep and 2 ins. wide, are cut in each stone oblique to the radius, so that the particles of material are driven to the periphery of the stones, and at the same time cut by the sharp edges of the furrows. The rotating stone, the upper one in Fig. 13, is driven by a spider and balanced by placing weights in recesses in its upper surface. The usual peripheral speed of su h mills is 1,500 ft. per minute, but with well-built and balanced stones a speed of 4,000 ft. or more may be safely used with corresponding increase of output. The heating of the material, or the stone producing damage to the product, or cracking in the stones, fixes the limit when the engineering work is satisfactory. When driven at a peripheral speed of 1,500 ft. per minute, the horse-power required for reducing standard limestone from $\frac{1}{4}$ in. size to 60 mesh is approximately one and a half times the diameter of the stone in feet, and the output under the best conditions will be 2 cwts. per horse-power-hour. Granite stones are best for unctious materials, such as steatite, graphite, etc., and also for soft substances. The amount of wear near the periphery is much greater than near the centre of the stones, and on this account they should be dressed slightly hollow, and, as soon as the outer surface ceases to grind, re-dressed. This operation is usually necessary every fourteen days and makes a serious repair bill.

The use of built-up stones of rock emery has made these mills capable of much higher efficiency and output, and avoided nearly all the usual dressing operations. The centre of the stone is built up of buhrstone, and the periphery only of rock emery ; no furrows are made in the emery grinding face, but slabs of sandstone are inserted radially and may be cut or serve the same purpose. The whole of the stones making up the millstone are held together by pouring molten metal, such as zinc, between the

joints. Such stones can be run at very high peripheral speeds, 5,500 ft. per minute, without fear of cracking or mechanical fault, and rarely need dressing. By the use of such stones the mills become suitable for reducing the hardest materials by grinding.

Similar mills are also made (Fig. 14) with hori-

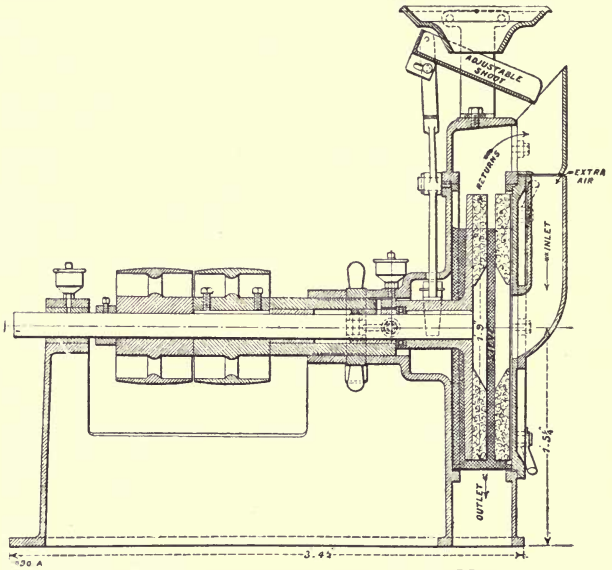


FIG. 14.—HORIZONTAL MILLSTONE MILL.

zontal shafts and vertical grinding surfaces, which are more compact and convenient for many classes of work.

Although all grinding machines have some advantage over crushing machines in the greater uniformity of the product, sifting devices are occasionally provided, as in Fig. 14, by discharging the product through a screen concentric with the stones, while

paddles fixed on the rotating stone lift the coarse material back to the feeder.

By using stones of different sizes, one of which is driven eccentrically to the other, which is mounted

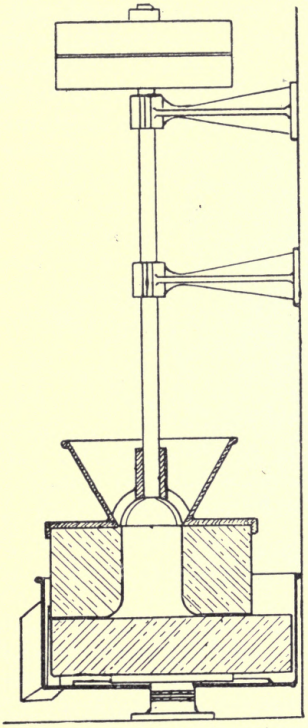


FIG. 15.—ECCENTRIC MILLSTONE MILL.

freely on a footstep bearing, the grinding becomes radial as in the similar coarse grinding machines, and the stones grind each other true.

The vertical eccentric mill (Fig. 15) is a good example, and is used for paints, black lead, chalk,

crayon and pencil masses. The upper stone only is driven, and rests with its weight on the lower stone. It is usually used as a wet grinding mill and, except for the charging of the rotating hopper, needs little attention.

There are many varieties of the eccentric mill which have doubtful advantage over the simple type. In one, both stones are driven, in another, the lower stone is made convex and the upper concave, the axis of the lower stone being inclined

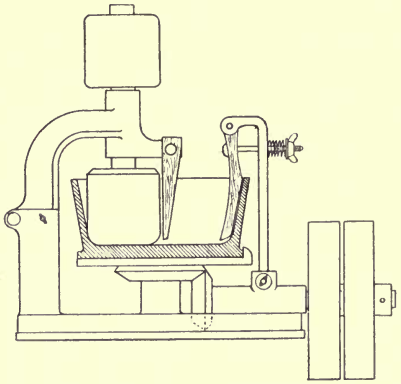


FIG. 16.—END RUNNER MILL.

to the axis of the upper stone, the object in most cases being to maintain even wear on the stones. The end-runner mill (Fig. 16), however, is an important modification of the eccentric mill. The lower stone becomes a mortar and the upper is reduced to a pestle or runner of half the diameter of the mortar, giving as large a capacity to the mortar as possible. Only in the smallest size is the runner driven. This mill is extremely valuable for laboratory work and small outputs. In the small sizes the runner is capable of being lifted and the mortar may be

removed for emptying. In the larger sizes an emptying slide is provided on the mortar. The mortars and runners are made of wedgwood porcelain, cast iron or granite, and the scrapers which continually bring the material into the grinding are usually of wood. The efficiency of the mill is not high unless fitted with screening arrangements, but its usefulness is great.

For the finest reduction and highest efficiency by grinding the roll mill is to be preferred. In its simplest form, a single roll, usually of granite, revolves against a concave block of the same material which is reciprocated in a direction parallel to the axis of the roll to equalise the wear. When grinding wet an additional roll may be used to feed the grinding roll with material, while a " doctor " or scraper is pressed against its surface to remove the material when ground.

Two-roll machines, similar to Fig. 12, except that the rolls are smooth, are often used for the dry reduction of starch, grain, and soft materials. The surfaces of such grinding rolls must not be polished, and any polish obtained by wear should be occasionally removed. In the case of steel rolls a sand-blasted surface is excellent, and in stone mills the surface left by a diamond turning tool is equally good.

Three-roll machines have their greatest application in the colour and paint trade. The usual type of machine consists of three equal rolls geared directly together, so that their velocity ratios shall be, for each pair, approximately $2\frac{1}{2} : 1$. The peripheral speed of the fastest roll from which the finished material is removed by a scraper varies from 360 to 600 ft. per minute. The wet material, paint or material in the form of a cream or very soft paste is fed between the middle and lowest speed rolls, which, where a bulk feed is given, are provided

with hopper cheeks to hold the material. The rolls are usually pressed together by means of stout spiral or flat springs, and the scraper is held in position by weights.

Another form of this triple roll mill is shown in Fig. 17. In this mill the fastest roll is mounted in fixed bearings and is larger than the other rolls. The feed roll is arranged to slide against the middle roll at an angle of 60 degrees or more, so that a bulk feed can be given.

By careful engineering the power required to do

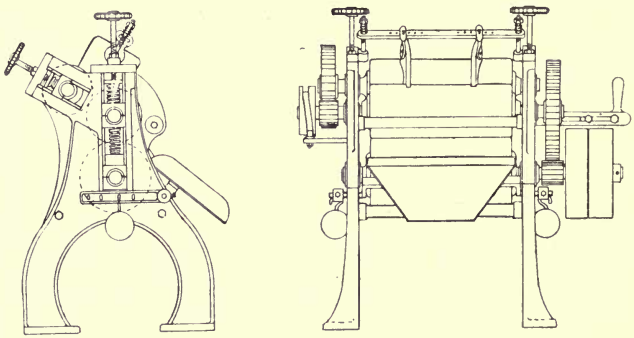


FIG. 17.—TRIPLE ROLL MILL.

a given amount of work on such mills may be reduced enormously in current practice. Many such mills are costing in power from 20 to 50 % more than necessary, and as a consequence the repairs and renewals accounts are also larger.

In overhauling roll mills, oval or badly worn spindles should be made true and the grinding surfaces turned true to the spindles by suitable means. Stone rolls are best turned by a diamond, mounted in a suitable holder, at a speed of about 25 ft. per minute with a traverse of about 50 to the inch, water being used as a lubricant. The operation

is slow, but needs no close attention except at the end of each cut. Emery wheels, which work faster, are not so satisfactory. Too much care cannot be taken in providing true rolls and mounting them in good bearings on a stiff frame with good adjustments. A good mill ought not to be allowed to work for more than twelve months without truing up. To equalise the wear on the rolls the middle roll in all types of three-roll mills is reciprocated through a distance of from $\frac{3}{8}$ in. to $\frac{5}{8}$ in. In some mills a simple cam on the roll itself is used to give this movement, but in the best mills a gear-box is provided to give a continually varying reciprocation. The amount of pressure required for the materials treated should be determined and maintained by strict rule. Such pressures vary from 12 to 30 lbs. per in. of width of roll. With pasty materials a pressure of 25 lbs. is usually satisfactory, but with paint or similar thin material 15 lbs. per in. is ample. The scraper is generally held by pressure against the revolving roll, at an inclination of about 75 degrees to the radius of the roll at the point of contact.

The scraper may be ground automatically in an emery wheel machine, and if in good order and fitted truly and flat to its support, needs very little pressure to remove the ground material. A badly fitted scraper will not "take off" under any reasonable pressure, so it is best to fix the pressure and thus detect bad scraper adjustments. A pressure of 1 lb. per in. of width of roll is common practice, but one half of this is better.

The simple way of gearing the rolls together in pairs by means of one cog wheel on each, gives considerable trouble when wear has taken place by the teeth "bottoming" and preventing efficient grinding. New gears of different pitch must be fitted in pairs to obtain the adjustment required.

High-class mills are now fitted with additional gear wheels mounted on quadrants, so that the wear of the rolls does not affect the adjustment of the gearing. In all such mills involute teeth should be used; cut gears are expensive but are most economical, machine moulded teeth are good, but wheels cast from wooden patterns are hopelessly bad and extremely noisy.

The power required for three-roll mills in good adjustment may be estimated as 1½ h.p. per foot of width of mill with a maximum surface speed of 400 ft. per minute. With badly adjusted mills and with sticky material the power required may be twice this amount.

Disintegrating Machines.

Size-reduction machines which act by disintegration or by blows on the unsupported particles are limited to a few types. Such machines, designed originally for use in the flour industry, can be used for all materials which break up easily and which are neither hard nor gritty. Limestone, quartz and materials which contain much moisture are quite unsuitable for treatment.

A well-known type is "Carr's" disintegrator (Fig. 18), which consists of several oppositely revolving cages, the bars of which, by successive impacts, beat the material to powder. The fineness increases with the peripheral speed, which in the case of the outer beaters is usually 7,200 ft. per minute. On degreased bones such machines will treat ·1 ton per h.p.-hour, while with coal ·4 to ·5 ton per h.p.-hour may be expected.

A very simple type of disintegrator is "Carter's," (Fig. 19), which consists of a circular chamber lined with chilled cast-iron plates and provided with circular screens, in which a disc carrying from two

to six beaters rapidly revolves. The chilled iron plates have grooved or racheted surfaces and the screens usually consist of triangular bars held at a suitable distance apart in a cast-iron frame. The width of the spaces between these bars determines the relative size of the discharged material, but is very much greater. The speed of the tips of the beaters varies in practice from 15,000 to 20,000 ft. per minute. while the outputs depend on the character of the material and the fineness required. A rough approximation to the output may be taken

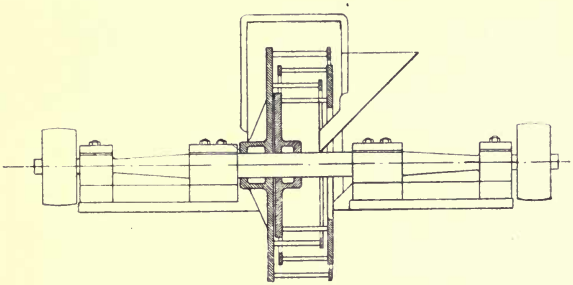


FIG. 18.—"CARR'S" DISINTEGRATOR.

to be $2\frac{1}{2}$ D^2 cwts. per hour of easily broken material, and the h. p. required 9 D — 4, D being the diameter across the beaters in feet.

The most economical way of working such machines is to use coarse screens and to sift or dress the product, returning the coarse material to the machine again. A few experiments will generally determine the best practice, and it is often possible to increase the output 50 per cent. by this means. The beaters act as fan blades, and drive a considerable amount of air through the machine, facilitating the work of screening and at the same time cooling and drying the material.

A defect of the type of machine is that with some

materials much heat is developed, and on this account water-jackets are occasionally fitted.

The machine may be mounted on a dust-tight wooden chamber with or without a hopper base, which receives the disintegrated material and is provided with a trunk for the discharge of the dust-laden air into a suitable dust chamber or dust balloon. The dust chamber is usually a framework

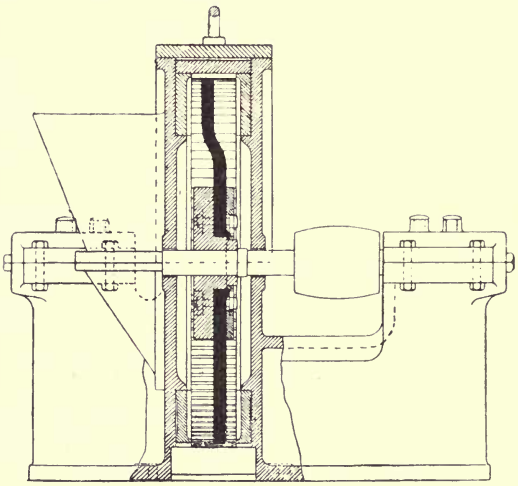


FIG. 19.—"CARTER'S" DISINTEGRATOR.

of timber carrying screening cloth through which the air passes, leaving the dust behind.

Dust balloons are also made of porous material and discharge their accumulated dust by means of a valve fitted to a spout at its base.

Another excellent disintegrator is the "Perplex" (Fig. 20). This machine is provided with a double set of beaters mounted on the face of a disc which protects the bearing from the disintegrating chamber.

A double set of screens and a discharge screen surrounds the whole. Owing to the excellent screening arrangements provided in the construction of the mill itself, a very even-sized product is obtained,

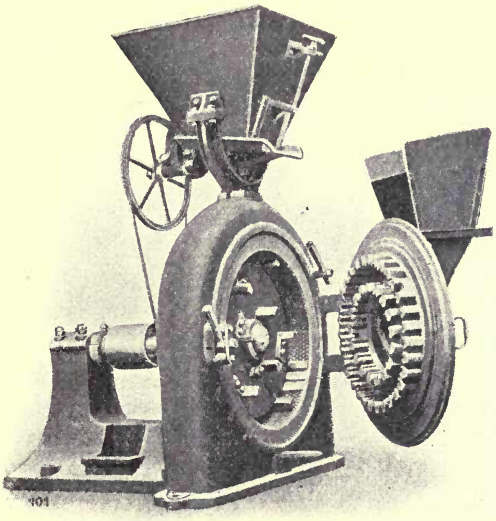


FIG. 20.—"PERPLEX" DISINTEGRATOR.

which, except for special market requirements, does not require dressing.

Stamp Mills.

In these machines, reduction is brought about mainly by crushing with blows upon the supported material. They are only used to a small extent in chemical factories, but in the allied mining and metallurgical industries have enormous application. The material to be crushed rests in a mortar, while blows are struck upon

it by a pestle. The pestle or stamp may be lifted by cams and allowed to fall by gravity, or steam may be used, so that the stamp mill becomes a modification of the steam hammer. In many types, air cylinders and springs are used to modify

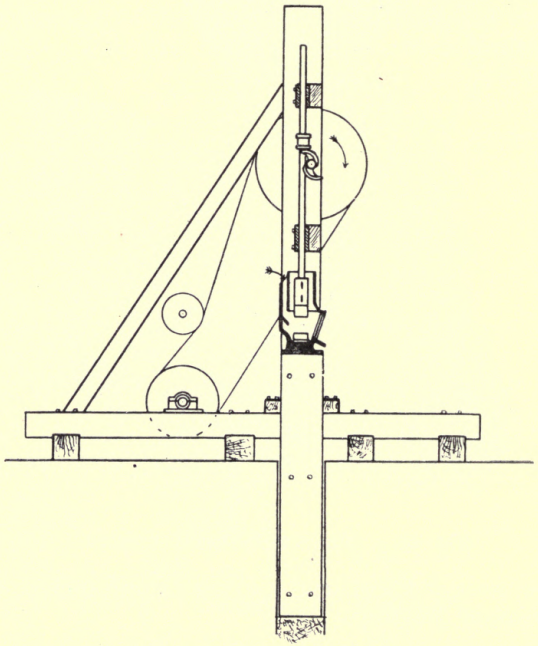


FIG. 21.—STAMP MILL.

the action of the stamp and to minimise the loss of energy due to unnecessary shocks. Since the principal wearing parts of such machines, viz., the die in the mortar and the shoe on the pestle or stamp, are cheaply and readily replaced when worn out, their capacity for reducing different materials of variable and great hardness balances their obviously

inefficient principle of action. As a rule, the mortar is partially or wholly surrounded by inclined screens upon which the crushed material is projected by the blow, and through which a greater or less proportion of finely reduced material passes, while the residue falls back on to the die to receive the next impact. This separation of the fine material from the coarse is incomplete, but is improved by the addition of water, which, by splashing through the screens, carries material with it.

In the ordinary stamp mill used by the mining engineer (Fig. 21) the weight of the stamp varies from 700 to 1,200 lbs., and the weight of the mortar from $2\frac{1}{2}$ to $3\frac{1}{2}$ tons. The screens are formed either of punched plate or woven wire. The most efficient screens are those which present the maximum area of opening with adequate strength. Punched plate screens are less efficient in action, on account of their smaller area of opening, and give less uniform product than wire woven screens, which, however, have a shorter life. Plate screens are usually punched with holes from ·03 to ·06 in. in diameter, the wire screens being 30 mesh, and giving more area of opening.

The height of drop of the stamps is determined by the condition of adequately covering the die with material to be crushed without causing undue wear on the die. The number of drops per minute is usually from 90 to 100, and the height of fall from 6 to 9 ins. The power required for such mills is usually $1\frac{1}{2}$ h.p. per stamp, and the output of pulp under good supervision 300 lbs. per h.p. per hour.

Small stamp mills with 200 to 250 lbs. stamps are sometimes used for crushing bones, phosphate rock, etc., but in this case the screens are very coarse. Still smaller stamp mills with globular stamps and cup-shaped mortars are used for crushing hard nuts, etc.

CHAPTER III.

SIFTING.

SIFTING consists in the use of surfaces with holes, called sieves or screens, for the separation of materials according to the sizes of their particles. It is an operation which is always avoided on grounds of economy, when possible. Useless wear and tear is a common accompaniment of screening processes, which are often badly arranged and thoughtlessly carried out.

In many industries the effect of crushing, moistening, or heating on the different constituents of the material often makes it possible for a simple screening process to separate them. A material which decrepitates may be separated from one which does not, by roasting and sifting, or by simply sifting in a heated screen.

The simplest type of sifter is the fixed inclined screen. The screening surface in this case may consist of a series of bars bolted together with distance washers between each to form what is usually called a " grizzly." Such bar screens, 3 to 5 ft. wide and 6 to 12 ft. long, are generally inclined in the direction of the length of the bar at an angle of 45 degs. In screening materials where the breakage of the large fragments should be avoided (*e.g.*, coal) the inclination should be made equal to or slightly less than the " angle of repose " of the material.

Fixed plate and woven wire screens are used in a similar way. Plate screens are punched with slots, whose length is in the direction of fall of the material ;

screens with circular holes are less efficient and give a product finer than the size of the holes. Woven wire screens (Fig. 22) formed of transverse stout

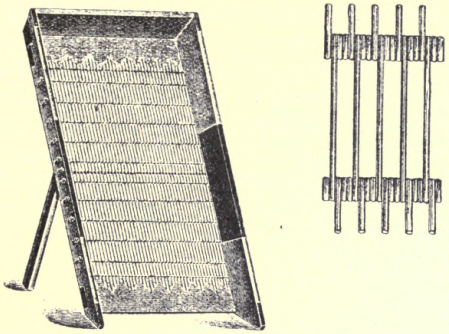


FIG. 22.—FIXED SCREEN.

wires, and fine longitudinal wires forming slots, are very satisfactory for fixed screens. For the sifting

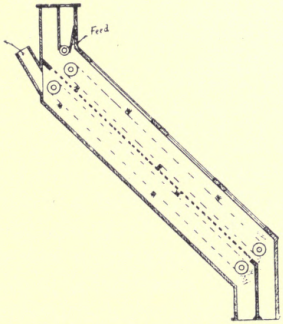


FIG. 23.—FIXED SCREEN IN CASING.

of sand and gravel the inclination of such screens is about 60 degs., and the material is thrown at the screen by means of shovels.

Fixed screens for fine sifting are often arranged in a casing (Fig. 23), a current of air being drawn through the screening surface to increase the rate of sifting, while brushes on simple chain conveyors, moving above and below, clean the screening surface or prevent its choking.

Fixed screen sifters in which the material is moved across the sifting surface by mechanical means, such as brushes, paddles, etc., are very common in chemical work. In the simple type shown in Fig. 24, the sieve is trough shaped, and a rotating brush with bristles arranged in a spiral manner carries the material along the screening

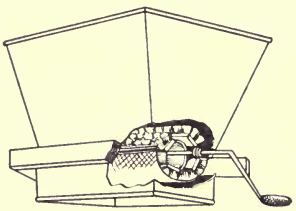


FIG. 24.—TROUGH SIFTER.

surface. The sifted material falls into the vessel upon which the sifter is placed, and the rejected portion is delivered into a small pocket at the extreme end. The brush is turned by hand, and a cover is provided to the hopper when in operation, to minimise the formation of clouds of dust. Power driven sifters of a similar type are often parts of other machines, and provide a preliminary treatment for the materials. A further modification is made by forming the sifting surface into a complete cylinder (Fig. 25), and fixing it in an inclined position in a suitable casing. In this case the spiral brush is arranged rather to lift the material, so that it is well brushed against the screening surface. This machine

is more suitable for materials which cake readily. A further modification consists in arranging a paddle wheel inside the screen which, on rotation, produces currents of air and throws the material against the screening surface. For coarse screening a horizontal screen with a central worm conveyor is often used, and, in some cases, lifting plates are fixed to the worm to turn the material over continuously.

In the most efficient sifting plant the screening surface is made to move, vibrate, bump or shake, and additional apparatus is arranged to prevent the screen from choking. Flat screens are arranged for

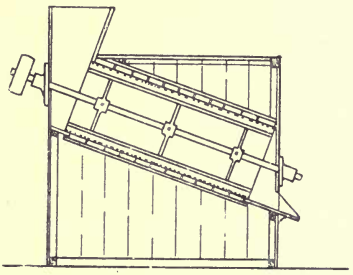


FIG. 25.—FIXED CYLINDRICAL SCREEN.

shaking, vibrating or bumping in a variety of ways. For small sifting operations the sieves are mounted in a drum with a charging space and cover above and a receiver below, and placed in a gyrating frame (Fig. 26). This frame is maintained in a horizontal position by means of suspension cords. In another type the frame strikes rubber buffers at each stroke.

A very efficient form consists of a series of sieves arranged in frames one above the other, and supported horizontally on vertical rods fitted at each end with ball and socket joints. The whole of the sieves are gyrated together, so that the material travels in circles, and is guided by pendent slats over

the screening surface to the exit openings. A travelling brush is also arranged to clean the screens

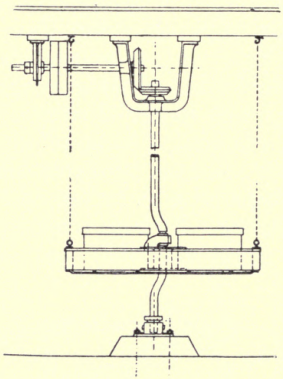


FIG. 26.—GYRATING SIFTER.

as the work goes on. A most convenient type of sifter, which may also serve as a conveyor, is shown

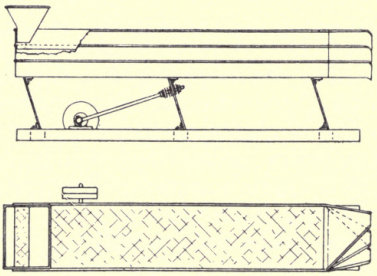


FIG. 27.—VIBRATING SIFTER.

in Fig. 27. In this case a number of sifting surfaces are arranged horizontally one above the other, each screen delivering its " tails " to its own spout, and

are supported in a frame on flat springs inclined about 15 degs. to the vertical. The action is that of the ordinary vibrating conveyor; a crank or cam vibrates the nest of sieves at a rate of about 300 strokes per minute, the length of each stroke being capable of variations from 0 to 1 in. The rate of travel of the material along the screens may be altered by adjusting the length of stroke. At each

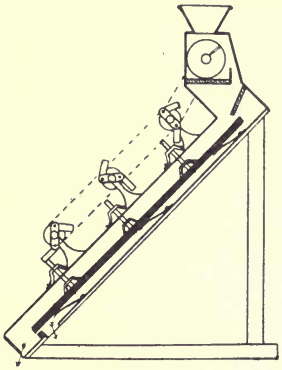


FIG. 28.—"NEWAGO" SCREEN.

stroke the material is thrown upward and forward, giving a very efficient sifting action.

Flat screens with gravity movement of the material are also vibrated vertically, or at an angle to their surfaces, which are in this case usually inclined 45 degs. In the "Newago" screen (Fig. 28) of this type, small hammers are arranged to tap the frame of the screen and prevent choking.

Screening surfaces of a cylindrical, conical or pyramidal shape, which revolve on a central axis, form an important class of sifting machines. The trommel (Fig. 29) is used for coarse screening, and consists of a cylinder of perforated steel plate,

mounted for rotation on an axle or on friction rollers. Cylindrical trommels are inclined at about 5 degs., so as to cause the material to slide rapidly through them. A common size of such machines is 5 ft. long and $2\frac{1}{2}$ ft. diameter, the speed being 20 revolutions per minute. Sometimes one trommel

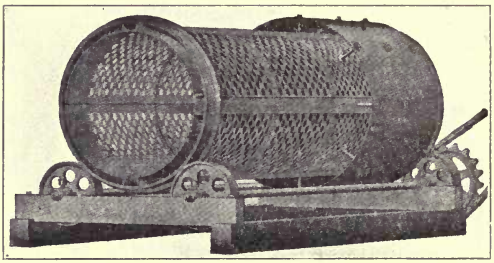


FIG. 29.—TROMMEL.

is arranged inside a second, so that two sifting operations take place at one time. Spiral screens, in which a continuous length of perforated plate is coiled in a spiral form, the coarser perforations being near the centre, also provide for more than one

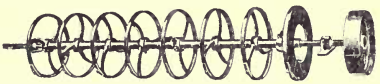


FIG. 30.—SKELTON REEL.

sifting operation. By the provision of stopping strips at points of the spiral, the discharge of the different grades of material at the ends of the screen is determined.

For fine sifting a series of circular supports (Fig. 30), or a cylindrical framework, is provided, upon which the screening material is stretched.

Such sifting "reels" are mounted in an inclined position in casings built in the factory. For materials which tend to clog, the circular form of reel is best, and an external rotating brush can be readily provided to clean the screening surface. For dry materials which do not clog hexagonal or octagonal frames may be used (Fig. 31). A worm conveyor is usually fitted in the base of the casing to discharge the sifted material.

In the sifting reel only the lower part of the

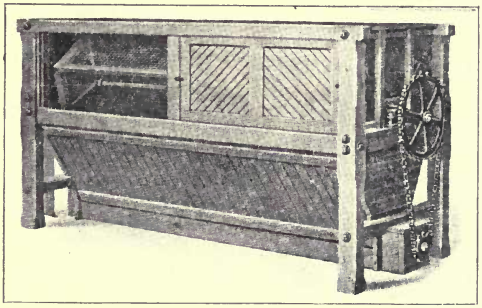


FIG. 31.—HEXAGONAL REEL.

sifting surface is in use, and its rate of working is consequently somewhat low. By the provision of a concentric paddle wheel turning with the reel, but not quite in contact with its surface, the material is lifted, and falls over the whole of the screening surface (Fig. 32).

A further step in rapid fine sifting consists in the provision of a paddle wheel with inclined blades or beaters (Fig. 33), which, rotating at a high speed, continually throws the material at the screening surface and produces a current of air, which increases the output enormously.

Such machines for the finest work are covered with silk stretched round the reel, laced in position, and held at the ends by means of spring clips.

The process of sifting does not lend itself to simple theoretical treatment, on account of the

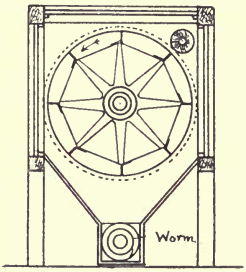


FIG. 32.—REEL WITH PADDLE ELEVATOR.

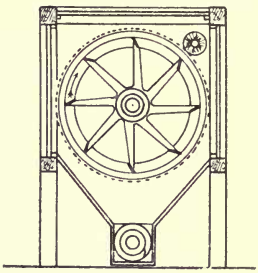


FIG. 33.—REEL WITH BEATERS.

influence of factors whose magnitude varies and cannot be closely estimated.

In fixed screens, trommels and reels the angle of repose of the material is an important factor.

ANGLES OF REPOSE OF MATERIALS.

Anthracite coal (2 ins. to $\frac{1}{10}$ in.)	27 degs.
Wheat	28 ,,
Bituminous coal (2 ins. to $\frac{1}{10}$ in.)	35 ,,
Sand, crushed ore	34 ,,
Ashes, soft ore	40 ,,
Finely ground coal (98% through 100 mesh)	16 ,,

With the finest ground materials, if dry, the angle of repose becomes small, and a curved surface of repose is assumed.

Another important factor is the relation of the

area of the openings in the sifting surface to the total surface, called the *opening factor*. The opening factor is always smaller for plate screens than for woven screens. If the holes in plate screens are punched $1\frac{1}{2}$ diameters apart, the opening factor, if the holes are arranged in equilateral triangles, is ·403, if in squares, ·319; at 2 diameters apart the figures become ·226 and ·196. In woven screens much higher factors are obtained, especially in coarse meshes. On the other hand, the life of the screening surface is shorter. The life of plate screens may be increased by increasing the thickness, since the holes may wear to a larger size before the screen gives way. A further advantage of plate screens is the fact that they do not choke so readily as woven screens.

Woven wire for screening purposes is produced by means of a loom similar to that used for cloth weaving. A series of wires are arranged at a uniform pitch to form the "warp," and the wire forming the "weft" or "shoot," passes above and below each wire of the warp alternately. In the loom, alternate wires of the warp are raised and depressed to allow the weft to be shot between and driven home by a comb or reed, and the operation repeated by raising the set of alternate wires which were depressed before, and so on. The kinking of the wire produced in these operations preserves the size and shape of the meshes, unless the wire be very thin.

It is obvious that the open space between the wires of the warp must be greater than the diameter of the weft wire, and that the diameter of the latter determines the finest limit of size of opening possible in this method of straight weaving. By using fine wire for the weft, and stout wire for the warp, comparatively fine screens can be made, but the practical limit of fineness is reached at 120 meshes to the linear inch.

Finer screening surfaces of wire are desirable, and

these are always produced by a variation of the weaving process called "twilling," in which sets of two or more wires of the warp are raised, and one or more wires depressed before passing the weft (Fig. 34). In this way, a more or less diagonal pattern is produced on the surface of the material.

Such twilled wire cloth is not well adapted for sifting, on account of the irregularity of the openings and its consequent tendency to choke.

In all wire-woven screens, exact truth of mesh is

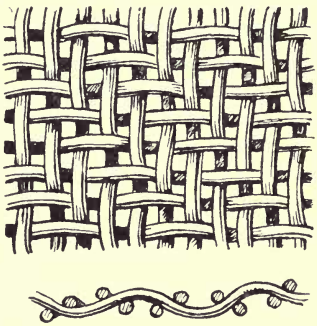


FIG. 34.—TWILLED WIRE CLOTH.

rarely obtained, the pitch of the weft wires is usually greater than that of the warp and somewhat irregular, owing to the character of the knocking-up process.

Silk gauze is produced in a different way on account of the fact that some device is necessary to preserve the meshes. In coarse meshes, two warp threads are used in place of one, and after the passage of the weft are twisted together. In finer meshes, single warped threads are introduced between the double threads, a sufficient number of double threads being used to effectively preserve the mesh (Fig. 35).

In very fine wire open mesh cloth, the mesh may

be preserved by passing two weft wires close together; the openings in this case are usually oblong.

There is a type of sifting surface which has recently come into great favour, which is formed by stretching a series of piano wires across a frame. It is, in fact, the warp of a woven wire screen without the weft. The wires are tightened up by keys, and are readily replaced when worn out; by the use of combs of different pitch the fineness of the screen may be modified to meet altered conditions. The wear of such screens is less than that of woven wire screens, not only on account of the hardness of the wire, but also because each wire gives way bodily to blows

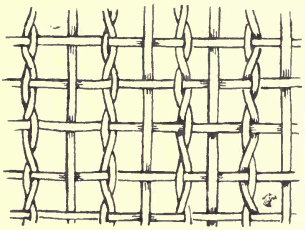


FIG. 35.—SILK GAUZE.

from the material. The opening factor of such screens is very large, and choking is practically absent.

By using very stout wires, flat and cylindrical screens are made which are adjustable in pitch. They present no advantage to the chemical industry for their increased cost, but in grain screening their use is extensive.

If a quantity of particles not too large to pass through its meshes be placed on a stationary horizontal screen, only a very small quantity will pass through before sifting ceases. Agitation, however, makes the sifting continuous, until all the particles have passed through the sieve. The failure of the

stationary sieve is, of course, due to "arching" of the material taking place at each opening, while the agitation breaks down the arch structure; but in addition to this, the agitation has another effect. It will be noticed, if the material in the sieve be watched, that the coarse material rises to the surface, and is the last to pass through. The higher bulk specific gravity of the fine material, together with its wedging effect, displaces the coarse material, and after a time the material on the sieve has separated into layers of different fineness. The finest material will thus pass through first, to be followed by coarser material, until that just small enough passes through with difficulty and probably some choking. The best sifting arrangements avoid this action of particles just small enough to pass through with the accompanying choking, excessive wear and small output.

If grading in size is to be carried out, it is better to remove the larger particles first, and the small particles last, relieving the fine screens from the weight, wear, and choking which results from the reverse procedure.

Where only the fine material is required, and the oversize is returned for further grinding, sifting plant in which separation into layers takes place by preliminary vibration is most satisfactory if economical work is to be effected. Knowing the percentage of fine material present, the length of screen surface necessary can be determined, and in the case of several sizes, relatively estimated.

Each movement of a sifting surface may produce a separating and a sifting effect, and it is convenient to consider the smallest movement which will determine the sifting of the lowest layer of particles as a "*sifting action.*" The size of the particles and the opening factor will determine the number of sifting actions required for dealing with a given depth of

material; or the number of particles just small enough to pass through the screen and capable of being contained in a given depth of material, divided by the number that will pass through at each sifting action, will give the number of sifting actions necessary to sift that depth of material.

What constitutes a sifting action in any sifting machine is determined by the relative movement of the material to the screening surface and sometimes by the pitch of the openings in the screen.

In vibrating screens, where the material is lifted at each vibration, the number of sifting actions is equal to, or a multiple of, the number of vibrations occurring, in the same time. In screens where the material slides over the surface the number of sifting actions will be a function of the relative velocity of the material and the pitch of the sifting surface. In piano wire screens the action is continuous, and determined by frictional conditions of the material with regard to itself and the wire surface.

TYPICAL WOVEN WIRE.

Mesh.	Pitch.	Diam. of wire.	Diam. of hole.	Opening factor.	Number of sifting actions per inch of depth.
4	·250	·0360	·214	·855	9
5	·200	·0320	·168	·84	12
5	·200	·0800	·120	·60	33
8	·125	·0220	·103	·824	20
10	·100	·0200	·080	·80	28
10	·100	·0480	·052	·52	100
20	·050	·0142	·0358	·716	78
50	·020	·0084	·0116	·58	366
150	·0066	·0028	·0038	·576	1,154
200	·0050	·0020	·0030	·60	1,319

There are obviously limits of speed above and

below which the rate of moving or vibrating would have no corresponding effect on the sifting operation. These limits are best determined experimentally, since they depend on many influences, the material, the screens, the production of air currents, etc.

Provided that the material does not cake or clog, it is possible to estimate with sufficient accuracy by these considerations the effect of changes in the

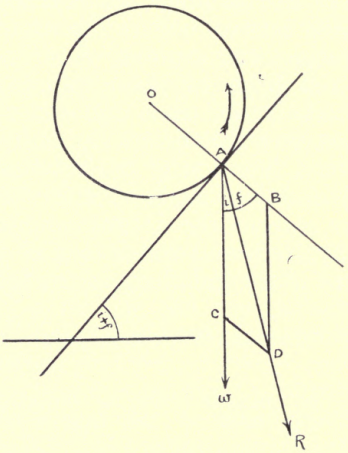


FIG. 36.

methods of working plant, or in the character of the sizing, and, with the help of a small scale test to closely estimate outputs.

Fine screening is much more difficult than coarse work, and on account of choking, demands generous estimating.

The effective area for sifting depends largely on the feeding arrangements, and varies with the fineness of mesh. For flat screens working nearly horizontally, a vibrating tray is much the best method of delivering a uniform feed, and in addition,

acts as a preliminary separator. The worm conveyor delivering through a slit is also used, especially for inclined screens. Five or six inches of screening surface at the sides of flat screens, and at the ends of cylindrical screens, are usually ineffective.

The height to which particles of material will rise in round screens, the effective screening area and the limit of speed can be readily determined if the angle of repose of the material on the screen is known.[1]

In the figure (Fig. 36), f is the angle of friction of the material on the screen, *i.e.*, the inclination of the tangent at the point where the particles slide, with the horizontal when the screen is at rest; i is the increase of this angle due to the rotation of the screen, so that $(f + i)$ will be the inclination of the tangent at the highest point A reached by the material, to the horizontal when the screen is in motion; r and v are the radius of the screen (in feet) and the velocity of its surface (in feet per second). If AC represents the weight of the particle, and AB its centrifugal force, and since each of these lines is at right angles to the horizontal, and the tangent at A respectively, the angle CAB $= (f + i)$, the angle CAD $= i$, and the angle DAB $= f$; also the angle CDA $= f$

$$\frac{\sin i}{\sin f} = \frac{wv^2}{gr} \div w$$

where w = weight of the particle,

$$i.e., \sin i = \sin f \frac{v^2}{gr}.$$

If the value of i exceed 90°, it is obvious that the particle cannot fall, *i.e.*, the limit of speed is given when

$$\sin f \frac{v^2}{gr} = 1.$$

[1] For a full discussion of this subject see "Ore Dressing," by R. H. Richards.

If f be taken as 35°, a common value, and the formula be modified to give N the number of revolutions per minute, then the limit of speed is given by the formula

$$N = \sqrt{\frac{5119}{r}}.$$

Knowing the angle at which the ore slides $(i + f)$ and the inclination of the screen j, the pitch angle p at which the material will slide with reference to the screen (describing a helix on the screen surface) can be readily seen to be given by

$$\sin p = \frac{\sin j}{\sin (i + f)}$$

and the distance l moved along the screen during one revolution will be

$$l = 2\pi r \tan p.$$

Or, if L be the length of the cylindrical screen, the number of revolutions n required for the travel of the material through the screen will be

$$n = \frac{L}{2\pi r \tan p}.$$

Since by altering the angle of inclination j of the screen an increase of feed can be given without altering the depth of material, an adjustment for the inclination of the screen provides a simple method of obtaining the maximum output for a given material.

The length of travel in all screening operations should be such as to provide, at least, the theoretical number of sifting actions for the size of particles, depth of bed, and character of screen in question. The amount of undersize in the oversize material after sifting varies enormously. In many industries

20% is considered excellent, and much larger figures are common.

In the mining industry, the preliminary sizing by sifting is often a preliminary operation before treatment by wet methods for separation according to specific gravity; but in most chemical work, the oversize is simply removed for further grinding, and it is an economic question which determines the amount of undersize present in the oversize or "returns" which is desirable.

CHAPTER IV.

Size Separation by Fluid Media.

The cost of sifting, on account of the wear and tear of plant and the slowness of the operation, together with the fact that fine sifting is always unsatisfactory, has compelled technical men to look for other methods of accomplishing the object in view.

In the mining industry where the separation of materials of different specific gravity constitutes a large portion of its activities, these other methods find their greatest development. By the use of currents of water or air, separation of particles, according to their specific gravity and size, can be accomplished with more or less practical efficiency. Where, as in the treatment of ores, the difference in specific gravity of the particles is the important consideration, a sifting process usually precedes the separation by fluid currents. The same process may, however, be used to separate by size, particles of the same material.

It has been noted that by agitating a granular material on a horizontal surface the larger particles rise to the top of the bed and the smaller travel to the bottom ; if, however, a current of water be driven upwards or forced in a series of pulsations through the bed, the reverse action will occur and the smaller particles will rise to the upper layer. If the water flows in both directions the action is more complicated and the small particles may travel downward if the interstices in the larger material are large

enough. In the operation of "jigging," which is based on these facts, the material is supported upon a screen while currents of water are produced in the bed formed, either by the up-and-down movement of the screen or by the action of pistons on the water itself. In a typical jig (Fig. 37) the material is fed on to one end of a fixed sieve A, where it is subjected

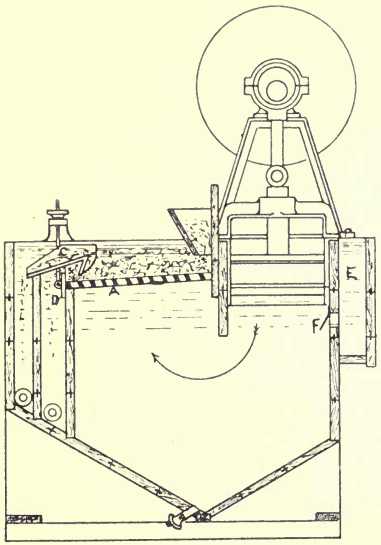


FIG. 37.—TYPICAL JIG.

to pulsations of water produced by the plunger B, and by the time it has travelled to the other end is separated into layers; the upper layer slides over the inclined shoot C and the lower layer passes under this shoot and over the adjustable sluice-gate D. The water is supplied by the trough E and passes through the valve F at each pulsation. Usually such jigs are placed in a row, the same material passing over the sieves of each in turn. Generally,

also, the fine heavy material passes through the sieve into the hutch G, and is removed at intervals. The shape of the hutch has a considerable influence on the action of the machine, and most machines are made of the shape shown. Such methods of size separation are rarely employed in chemical work, but a method of separation called elutriation or washing, which consists in taking advantage of the different rates of settlement in water of different sizes of material is common. After levigation or fine grinding in water and in the case of many natural materials—clays, steatite, barytes, graphite, starch, etc.—this process is most useful.

In this operation, as still carried out in many factories where small quantities of very finely divided material are required, the substance is stirred or ground with water, run into a vat, and allowed to stand for a few minutes. The pulp above a certain distance from the bottom of the vat is then run into settling tanks where it may stand for several hours or days for complete settlement. The clear liquid is syphoned or run off and the sludge removed to suitable drying or other plant. In the case of the finest clays, a week or even a month may be taken for settling, but with most materials the operation is complete in three or four hours.

For large outputs, and where the time of settlement is not too great, long troughs in series are used through which a continuous and carefully regulated flow of pulp is allowed to pass. These troughs may be from 50 to 100 ft. long and the slope about 1 to 2 ins. in 100 ft. Any very light material such as woody matter does not deposit, while the coarse particles settle near the entrance to the trough and the finest near the weir at the exit.

Such plants are very cumbersome, and many attempts have been made to produce compact machines for dealing with such problems efficiently.

The most satisfactory methods depend on the use of centrifugal machines, by means of which a force of settlement can be produced which is much greater than that due to gravity alone. In Gee's apparatus (Fig. 38) the liquid carrying the suspended particles is passed through a tube driven at a high speed by the pulley B and provided with radial divisions driven by the pulley A at the same speed so that the liquid moves with it. The suspended matter deposits on the lining of the tube, and, after the operation, is removed in cakes, in which the fineness of the particles varies from one end to the other. By cutting the cakes transversely the material is divided into different qualities according to the degree of fineness. The separated material can also be removed as a thick pulp by driving pulley A alone.

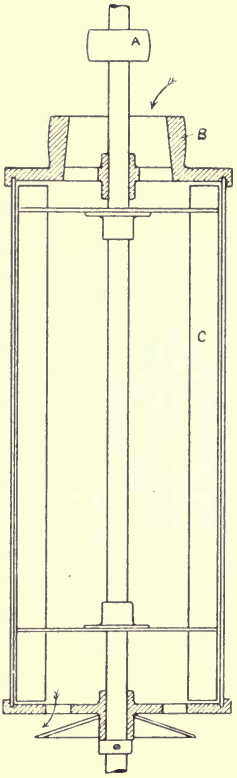


FIG. 38.—GEE'S APPARATUS.

Where, however, comparatively coarse material is to be removed from fine material the Freygang elutriating plant (Fig. 39) is probably more convenient. The tube A, mounted on trunnions for adjustment, contains a screw conveyor which continually lifts the material which is fed into the hopper B. Water is also fed into this hopper at a definite rate and overflows at C carrying with it suspended particles, the

fineness of which depend on the rate of flow of the water and the speed of the conveyor. The large size material is discharged above the water line in the apparatus at the spout D. For closer separation several such apparatus may be used in series.

The operation of this type of plant may be theoretically considered and compared with the facts of practice. When a particle falls in a liquid it encounters a resistance to its motion which depends on the velocity acquired and which causes it rapidly to assume a constant velocity. With very small

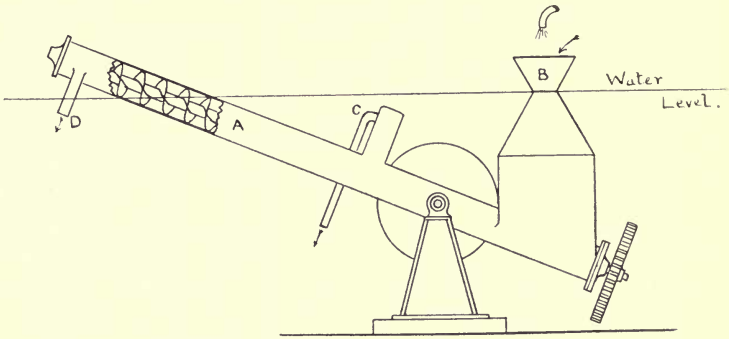


FIG. 39.—FREYGANG'S ELUTRIATOR.

particles and consequently low velocities, the resistance is mainly due to the viscosity of the liquid and Stokes' law is closely followed—

$$V = \frac{1}{18} g D \left(\frac{d-d'}{\eta}\right)$$

where all dimensions are in C.G.S. units.

D = the diameter of the spherical particle.

d = density of the particle.

d' = density of the liquid.

g = Gravity constant.

η = viscosity of the liquid (for water at 20° C. $\eta = \cdot 010$).

The velocity is therefore proportional to the square of the diameter of the particle and the difference between the specific gravities of the particle and the fluid. The critical size of particles above which the law fails is approximately ·008 in. for sand in water, the critical velocity being about 1 in. per second. For heavier materials the critical size would be less and the critical velocity somewhat greater.

Above this critical velocity the formation of eddies changes the character of the resistance until it becomes approximately proportional to the square of the velocity, and the velocity acquired is proportional to the square root of the diameter of the particle,

or $$V = K\sqrt{(d-d')}\,D$$

where K is a constant depending on the units employed. Using C.G.S. units as before the value of K for sand in water is 27·5.

These generalisations, which state the facts, approximately, for particles falling freely or under "free settling conditions," need some correction to represent the practical conditions in which mutual interference between the particles takes place or under "hindered settling conditions."

A simple correction which meets the extreme case is obtained by substituting the average density of the fluid and the particles for that of the fluid in the formulæ given. In actual practice the results lie somewhere between free settling and hindered settling conditions.

Wet methods of size-separation are often undesirable, and in many cases dry separation is essential. By the use of currents of air instead of water, dry separation with very finely-divided material can be accomplished, but when the separation is required

to be close the results are not so satisfactory as with wet methods.

A simple plant for dry separation is shown in Fig. 40. The material is fed at a regular rate into the hopper H, and falling, meets a horizontal jet of air from the slit A ; the coarser material falls into the chamber B, the fine passes into the chamber C, and is removed by the worm D. The fan E circulates the same air continuously so that the finest dust is not discharged into the atmo-

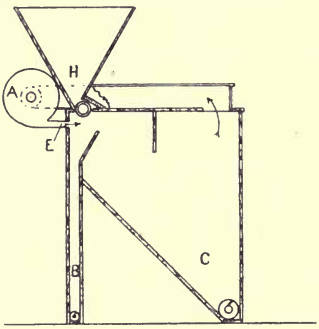


FIG. 40.—DRY SEPARATOR.

sphere. The maximum difference of pressure in such apparatus is about 12 ins. of water column, and a number of similar jets vertically arranged are often employed. It is obvious that perfect adjustment of the feed and absolutely even running of the fan are essentials to success. By fixing the fan centrally and arranging the other parts in cylindrical form a very compact form of the apparatus (Fig. 41) is obtained. This type is used in large numbers in place of screens. The material falls on to the feeding plate A, which is rotated by the pulley B. The lower part of the hopper is rotated by the pulley C,

and carries the fan D. The relative speeds and the distance apart of the base of the hopper and the feeder plate can be adjusted to suit the material. The smaller particles are carried forward by the current of air produced, through the slits E into the

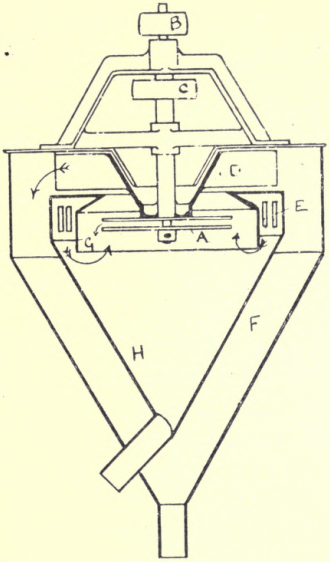


FIG. 41.—CYLINDRICAL SEPARATOR.

chamber F, while the large particles strike the cylinder G and fall into H.

A similar arrangement of parts is often provided in dry grinding plant, the current of air removing the material from the grinding zone and returning the large after being separated from the small, which in this case is the finished product.

The principle of the jig has also been applied for the size separation of materials, but since the mass

action of the particles conflicts with their action in the jig, such machines are only suitable for separating according to specific gravity, and then only when water is unavailable. This failure may also be anticipated from theoretical considerations. The motion of the particle may be expressed by the equation

$$AD^3d\frac{dv}{dt} = AD^3(d - d^1)g - BD^2vn$$

where A and B are constants, D is the diameter of the particle, v is its velocity and t represents time. At the instant of th commencement of motion, *i.e.*, when $V = O$, it will be seen that $\frac{dv}{dt} = \left(\frac{d - d^1}{d}\right)g$ or, that the acceleration is mainly determined by the density rather than by the size of the particle.

CHAPTER V.

Separation of Solids by Magnetic Methods.

The magnetic properties of different materials may determine a convenient method for their separation, but the use of this property for the separation of feebly magnetic material has only become important during the last few years, although the removal of pieces of iron, nails, etc., from raw materials by magnetic separators constitutes the first operation in many industries.

In magnetic separators a stream of material is brought under the influence of movable or stationary magnetic fields, which either hold, withdraw, or deflect the magnetic material from the main stream. For simplicity, there may be said to be two classes of machines: (1) lifting machines, in which the magnetic material is bodily raised out of the moving stream; (2) deflecting machines, in which the magnetic particles are deflected in a falling stream. Each of these classes may be subdivided into types and modified for working in water. The simplest type of the first class of machine consists in suspending permanent or electro-magnets over the stream of material carried on a conveyor or in a shoot. The attendant, who removes the material as it accumulates, is usually employed at the same time in removing by hand any other defective material that may be present. Such a crude plant is only justified in rough operations or where careful examination or picking takes place.

When close magnetic separation of feebly

magnetic material is required, the material must be reduced to a uniform size dependent on its character and the closeness of the separation. A good type of lifting machine is shown in Fig. 42, a variety of the "Wetherill" separators. The material is placed in the hopper A and fed in a uniform layer to a depth depending on the character of the material and the separation required, on to the travelling belt B. At the points C and D magnetic fields are produced by means of the electro-magnets E. The upper pole piece is made in the form of a wedge while the lower pole piece is a flat surface, so that the magnetic

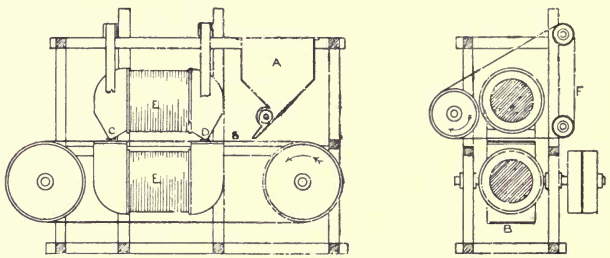


FIG. 42.—"WETHERILL" MAGNETIC SEPARATOR.

potential is enormously increased in the neighbourhood of the upper pole, and very feebly magnetic particles are readily lifted from the bed. The lifted material is usually removed by another travelling belt moving in contact with the upper pole so that it receives the magnetic particles on its lower surface. These belts are generally placed at right angles to the feeding belts, but other positions are common. The edge of the upper pole piece is generally inclined to the feeding belt at the angle of the resultant velocity of the feeding and taking-off belts. The speeds of these belts are always determined by trial and vary from 100 ft. per minute for feebly magnetic material to 1,000 ft. per minute where separation is

easy. The distance apart of the belt surfaces varies in practice from $\frac{1}{2}$ in. to $1\frac{1}{4}$ ins., the width of the feed belt being 18 ins. and that of the taking-off belts 3 ins. Bronze shoes are fitted on the pole pieces to take the wear of the belts, and in the case of strongly magnetic material the lower shoe is made very thick or the pole itself is increased in area to facilitate the lifting action of the field.

A modification of this machine, in which the taking-off belt travels in the same direction as the feeding belt, is shown in Fig. 43 and is more suitable

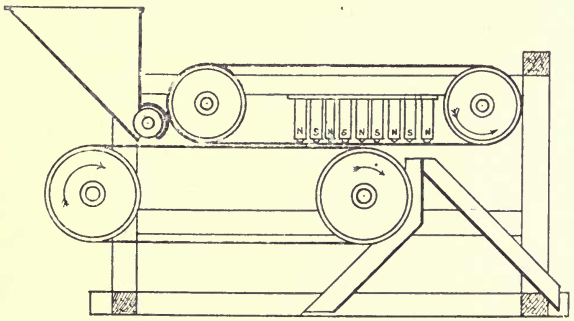


FIG. 43.—BALL-NORTON MAGNETIC SEPARATOR.

for strongly magnetic material. A series of magnets with their poles alternating are placed above the belt, and by the consequent agitation of the attracted particles prevent entanglement with them of non-magnetic material. The energy required for such machines varies from 1 kw. for easy work to 10 kw. for difficult work, and the rate of working may vary from 1 to 15 tons per hour according to the speed of the belts and the depth of the bed.

The most important class of machines are those which act by deflecting the magnetic material. In the magnetic drum (Fig. 44), which is most commonly used for separating nails, etc., from raw materials,

internal magnets are provided to produce a series of magnetic fields at its surface. The material is fed into the hopper A and shaken down the shoot D, which is agitated by the cam shaft B. A small pulley on B drives a larger pulley on the magnetic drum shaft at C. The non-magnetic material falls on the shoot F, while the magnetic material is carried under the machine and falls on the shoot G. The

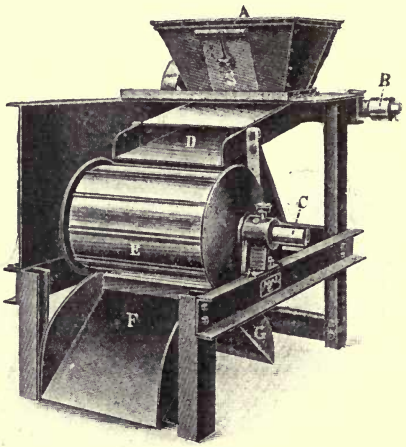


FIG. 44.—MAGNETIC DRUM.

magnetic fields on the surface of the drum generally terminate at the lowest point of the drum, and in some cases a mechanical method of cleaning the drum is provided just beyond this point.

An ordinary belt conveyor is often modified by providing a magnetic drum for carrying the belt at the delivery terminal, with suitable shoots for receiving the separated materials. This arrangement is valuable on account of the saving in head-room and also in cost.

By providing a series of drums and running them at different speeds the material may be subdivided into several grades according to their magnetic qualities. In the "Monarch" separator (Fig. 45) the magnetic drum A performs a first separation, and the separated material is again treated by the second drum B. By running B at a higher speed, or by using weaker magnetic fields, a portion of this material falls into D while the highly magnetic particles are discharged at E.

In other types of machine a magnetic field is formed at the surface of the drum by an external

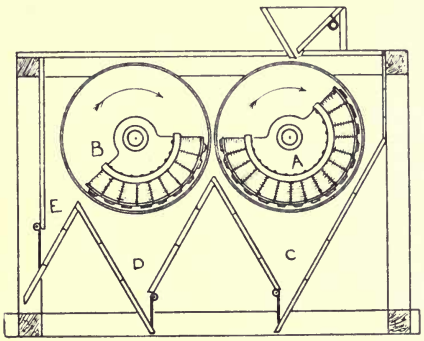


FIG. 45.—"MONARCH" MAGNETIC SEPARATOR.

magnet. In the "International" separator (Fig. 46), the drum consists of a series of laminated iron discs whose edges are formed into teeth, to give a more concentrated field at definite and regularly arranged points on the drum surface. The drum is rotated at a superficial speed of 300 ft. per minute, and the material is carried by it into the air space of the magnet, contact with the pole being prevented by a brass liner. The magnetic field is strongest at *b* and becomes weaker until at *a* a neutral point is reached. The non-magnetic material falls from the

point *b*, while the magnetic material is deflected and falls into the shoots C and D. By careful adjustment of the shoots strongly magnetic material can be separated from feebly magnetic material and also from non-magnetic or dia-magnetic material with commercial success, but as a rule two treatments of each product are necessary. In another type of machine the rotating drum is omitted and a travelling band running over the polished end of the pointed pole piece carries the material to the mag-

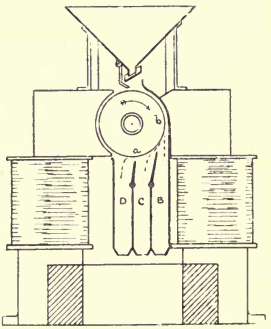


FIG. 46.—"INTERNATIONAL" MAGNETIC SEPARATOR.

netic field ; deflection of the magnetic particles takes place as the material falls.

The treatment of sands and other finely divided material for the separation of particles of the same specific gravity but of different magnetic permeability is daily accomplished by the use of these machines.

For the preliminary treatment of bones, phosphates, copra, etc., the cheapest and most efficient device is shown in Fig. 47.

The shoot is inclined at an angle of about 45 degs., and as the material passes down it any iron fragments are deflected and held by the magnet poles out of the

way of the main stream. At intervals, of course, the accumulated iron must be removed by stopping the feed and switching off the current.

Separation of Solids by Electro-static Methods.—A method of separation has been developed during recent years depending on differing electrical conductivities of the particles. When a stream of material is brought into contact with an electrically charged body, the good conducting particles become similarly charged and repelled at once, while those

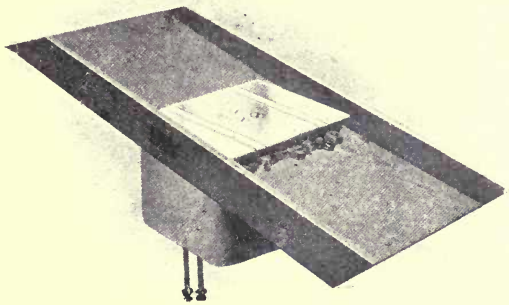


FIG. 47.—MAGNETIC SHOOT.

which are bad conductors continue for some time to be attracted. If in addition all the material be charged with electricity of opposite sign before being brought into contact with the charged body a more definite separation of particles takes place.

The principle of such machines is illustrated by Fig. 48. The material sliding down the shoot A becomes charged, and falling on the rotating metal roller B, which is charged to an opposite sign, is separated into streams according to the conductivities of the individual particles. An electrode C charged

to the same sign as the shoot intensifies the electrical field and improves the separation.

The electrical charges were at first supplied by induction machines, but these were only satisfactory in good weather and with the best supervision. An

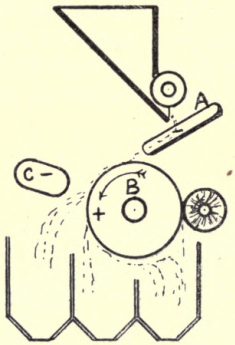


FIG. 48.—ELECTRO-STATIC SEPARATOR.

alternating current of high potential is now rectified for the same purpose. Variations in size of the material must be avoided and the separation is much affected by uneven dryness. With careful reduction and sizing the method is becoming most useful for concentrating graphite, molybdenite, blende and sulphides generally.

CHAPTER VI.

Mixing Operations.

Although mixing operations are continually being carried out in chemical factories, they are often most inefficiently performed. The mixing of solid materials presents difficulties which are often shirked rather than faced, with a resultant increased cost in later operations or lower quality and efficiency generally. The commercial loss is often far more serious than is usually imagined.

Uniform mixing of dry materials of different specific gravity or size is practically impossible. On this account materials are often mixed by being ground together without any previous attempt at mixing. In some cases a small percentage of liquid is added to increase the internal friction and thus tend to stop separation.

The ball mill is commonly used, both wet and dry, for simultaneous grinding and mixing. For batch-working, the closed mill is most convenient, and may be worked as a dry mill, provided that the liquid ingredients do not exceed 2%, or as a wet mill when they exceed 50%.

For continuous working the continuous ball mill or tube mill is often used, the ingredient being fed by simple measuring devices at one end of the mill, while the mixed and ground product leaves at the other. Where it is essential that coarse and fine material be mixed uniformly and no grinding is permissible, the balls are omitted, and internal projecting vanes are provided to turn over the

material and produce a satisfactory mixing. Where very fine grinding is required, together with absolute uniformity, as in the manufacture of high class plastic and other compositions, a dry mixing of the

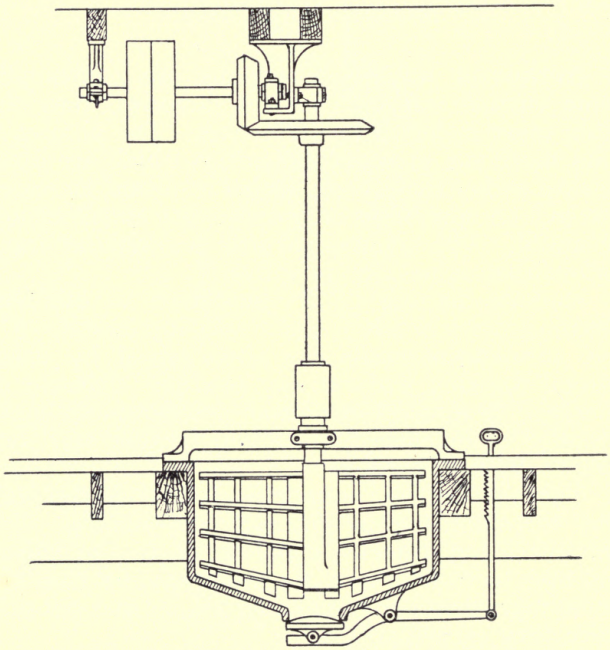


FIG. 49.—VICKERS' MIXER.

finely divided materials should always be made in the first instance, or small variations in composition will not be avoided.

The edge runner mill is often used for grinding and mixing at the same time, and its work is most satisfactory, although the output is small.

A simple mixer for dry or wet mixing where no attempt at grinding takes place is shown in Fig. 49. This represents the Vickers' mixer which is used in many manure works. The pans are usually 5 ft. in diameter, hold 1 ton of material, and take 5 or

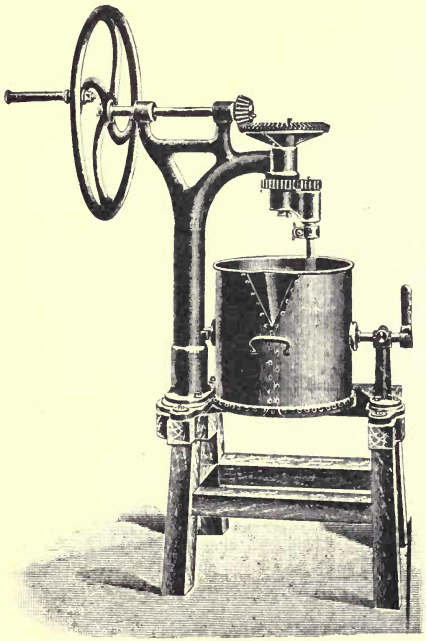


FIG. 50.—SUN AND PLANET MIXER.

6 h.p. for driving. The provision of a discharge valve at the base enables the workman to discharge and charge again without stopping the rotation of the paddle.

In another form of mixer the paddle rotates in a circle smaller than the pan, but travels round the pan by means of sun and planet gearing. In the

machine shown in Fig. 50, the paddle may be removed after mixing and the pan turned on its trunnions for emptying. By the provision of a stoneware pan and paddle, this machine can be readily adapted for strong acid or alkali mixings. In some types of this machine, the pan and paddle are separated by means

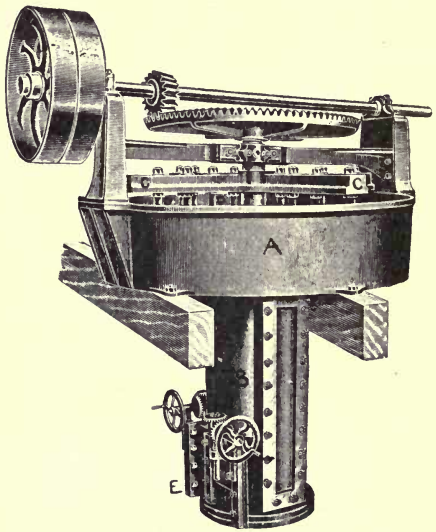


FIG. 51.—PUG MILL AND MIXER.

of a vertical screw or a rack and pinion, or by the provision of a long key-wayed spindle to the paddle. The pans of these machines are often steam-jacketed when used for pastes, and in some cases the paddle is made hollow for the same purpose.

The ordinary pug mill of the clay worker is a crude mixing machine for plastic materials, and is often provided as shown in Fig. 51 with a m xer for the dry clays used. The mixer consists of a flat

pan A mounted above the pug mill B ; the spindle of the pug mill, in addition to its pugging knives, carries arms C, provided with mixing blades D. The dry clays are continuously introduced near the periphery, and the requisite quantity of water added.

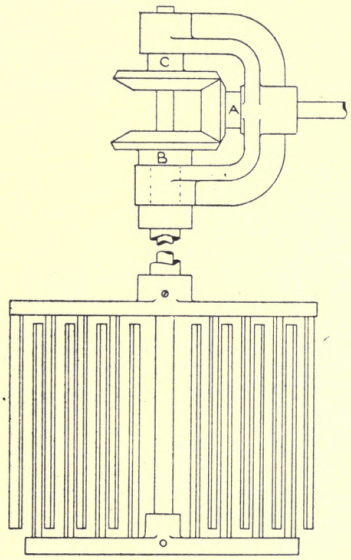


FIG. 52.—DOUBLE PADDLE.

The mixed and pugged clay is discharged from the adjustable outlet E near the base of the machine.

A pair of concentric paddles are often fitted to small mixers and increase considerably the efficiency of the machine. As shown in Fig. 52, the upper paddle is fixed to a sleeve carrying the gear wheel B and the lower paddle to the spindle carrying the gear wheel C. On rotation of the gear wheel A, the paddles rotate in opposite directions. Such machines

are also used, by rotation at a high speed, as whisking machines for the production of air and liquid emulsions or for the formation of porous plastic and other masses.

Vertical mixers with two spindles are not often met with, except in factories producing emulsions, margarine, etc., where they appear to be the standard machine.

The mixing paddle of vertical spindle mixers is made in many forms. In pug mills and simple

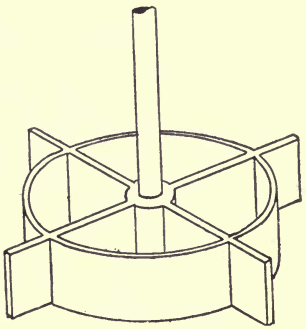


FIG. 53.—NIAGARA PADDLE.

types of mixers a series of projecting knife blades set at a slight angle seems effective ; for fine powders with mixers having bowl-shaped containers, a narrow helical blade, which continually moves the material next the sides of the container, is excellent ; with cylindrical containers, the Niagara paddle, Fig. 53, does excellent work if the depth of the material is not too great. This paddle is also used for maintaining solids in suspension in liquids, when the cross slats are often omitted and the circular part is formed into a hollow frustrum of a cone tapering above or below. This paddle, Fig. 54, is the most

efficient for mixing liquids. Paddles with projecting knives or wooden slats which pass between similar projections from the sides of the container are common.

Although the provision of a bearing for the paddle in contact with the mixture is not desirable, this construction is generally adopted on grounds of economy. Such bearings usually consist of a vertical pin mounted on the base of the container, fitting into a recess at the end of the paddle spindle.

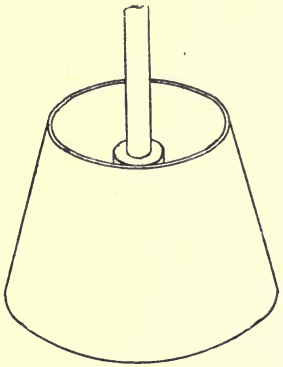


FIG 54.—CONICAL PADDLE.

This construction allows the material treated or grit to fall from the bearing rather than into it. With wooden paddles or spindles, the pin is made of a hard wood like lignum vitæ, working in a bearing of similar material let into the shaft. With metal paddles the pin is often conical. A thin disc of hard graphite or of fired steatite-clay composition is often inserted for lubricating purposes. A recess containing stiff grease or petroleum jelly is another method of lubricating, but if the vertical pressure is taken on a collar outside the container, lubrication of the footstep bearing may not be necessary.

Of mixing machines with horizontal spindles, the "Gardner," Fig. 55, is the best known. The paddle consists of a series of helical blades set in opposite directions, which on rotation throw the material backwards and forwards in a semi-cylindrical trough. A brush sifter BC is usually added to ensure the absence of lumps, and discharge is made by means of a sliding plate at I. For cleaning purposes

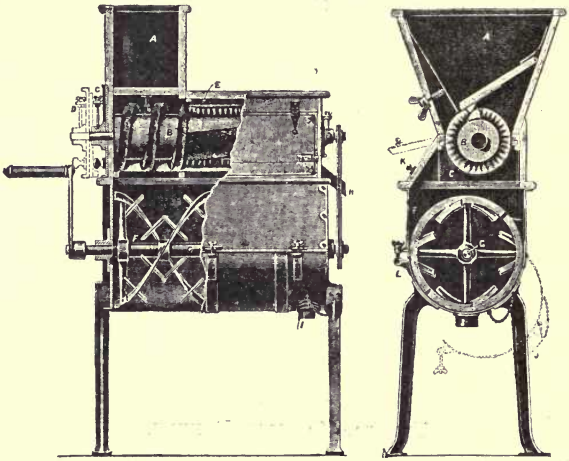


FIG. 55.—GARDNER MIXER.

the lower part of the mixer may be dropped by releasing the fly nuts at L.

Worm conveyors are often modified at one part to act as mixers in a similar way; the trough is enlarged and the worm modified as in the "Gardner" machine for mixing.

Two spindle mixing machines are not common on account of their greater cost except for mixing plastic materials where single spindles obviously fail, by the mass moving as a whole. The "Uni-

versal" machine, Fig. 56, is a type of this class;

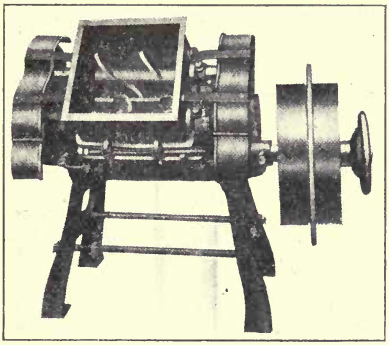


FIG. 56.—UNIVERSAL MIXER.

the blades vary in shape according to the consistency and character of the material.

The blending of greases, butter, margarine,

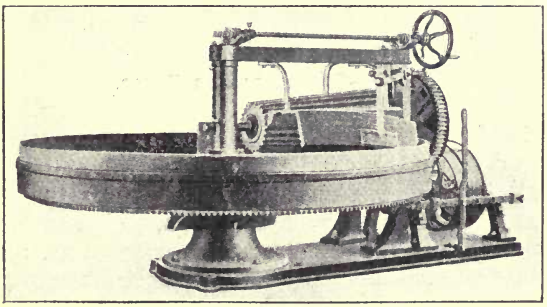


FIG. 57.—BUTTER WORKER.

etc., is generally carried out in butter workers, the usual type being shown in Fig. 57. For this class of work, the fluted roller and bed of the

machine are made of hard timber, beech by preference, and the rusting of the iron framework supporting the bed is prevented by cementing the timber to it by means of asphalte. Other butter workers, or kneading machines are provided with double worms which force the material after kneading through dies of suitable form for making cakes. Such machines are called plodding machines, and in many factories the ordinary " Enterprise " meat chopper is adapted for this work by modifying the die plates. With stiff plastic material hydraulic presses are often

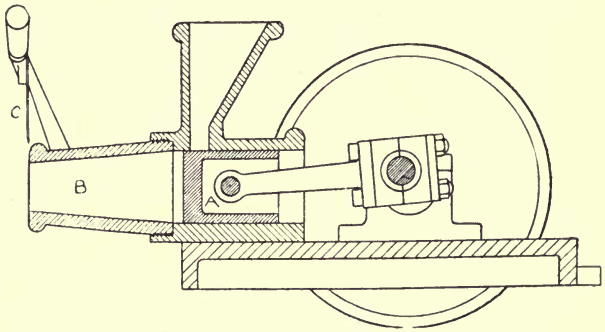


FIG. 58.—CONSOLIDATING PRESS.

used to force the material through a screening surface and through die plates having small holes. Immediately under the die plates a revolving cutter divides the sticks into small pieces, which are then thoroughly mixed in a mixing machine and again consolidated in a suitable press. A mechanical press for consolidating such stiff materials is shown in Fig. 58. The material is fed into the machine slowly and at each stroke of the piston A, a hammer blow consolidates the material and forces it through a taper nozzle B, while the imprisoned air escapes on the back stroke of the piston. The cakes of material

are cut off at suitable intervals by the knife C. This machine has been modified for hydraulic pressure, and by connection with a vacuum pump at each charge the imprisonment of air in the material is prevented.

For the stiffest masses, mixing is most readily accomplished by means of rolls, Fig. 59. These revolve in opposite directions at unequal speeds, and continually knead and masticate the material.

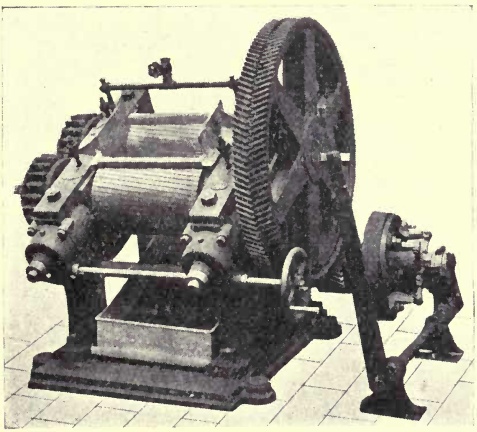


FIG. 59.—MIXING ROLLS.

This is the standard machine of the rubber and celluloid industries. To facilitate the work the rolls are often steam-heated, especially when solvents are associated with the material, which must be driven off. The surface speed of these rolls is about 120 ft. per minute, and the difference in speed is usually small. When the rolls run at equal speed, the time required for mixing is rather great and when the difference in speed is great, the material is torn and not consolidated so that

its strength is reduced largely on account of a lack of homogeneity. A difference of 10% appears to be satisfactory in most industries. When working plastic mixtures made with solvents, the rolls are at first kept near together, and are opened as the mixing proceeds and the stiffness increases, the rate of evaporation of the solvent diminishing as the thickness on the roll increases. The material tends to adhere to the fastest roll and with many plastics forms a tube on this roll, which by being cut longitudinally may be removed from the machine as a sheet ready for the moulding processes.

CHAPTER VII.

The Transport of Solid Materials.

The common wheelbarrow is most extensively used in chemical factories for transport purposes where changing conditions or occasional use renders the installation of conveyors or tramways unremunerative.

An ordinary labourer can transport ·5 ton of material per hour per 100 yards, so that the cost of such transport will be 8*d.* to 10*d.* per ton per 100 yards. In rapid working the barrows are filled by a shoveller and trundled by a wheeler; the proportion of wheelers to shovellers is estimated for earthwork by the fact that a shoveller can fill a barrow in about the same time as a wheeler can wheel it 30 yards, tip it and return with the empty barrow; 1 yard of rise is usually taken as equivalent to 6 yards in horizontal distance. An iron plateway should be laid where much barrow work is done, both to ease the work and to reduce the road repairs.

Trucks with two wheels, on which the load is practically balanced, are more suitable for heavy loads, especially where iron plate tracks are provided. Light four-wheeled waggons provided with tyres suitable for plateways or railways are, however, more generally efficient. Such railways are supported overhead for charging furnaces, etc., and the waggons are pulled by means of an endless cable.

The tractive effort required for pulling such trucks on a level is usually estimated at 30 lbs. per ton of total load. Runways, *i.e.*, overhead rails

carrying a small trolley which is provided with a hook from which a skip is suspended, are also of great utility for charging purposes, and are both inexpensive in first cost and in working.

When horses are employed in hauling waggons one horse may be expected to transport 8 tons at

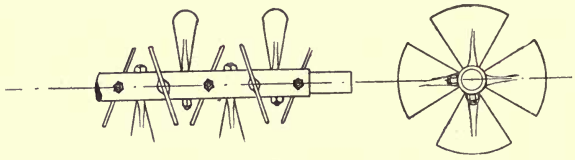


FIG. 60.—PADDLE TYPE OF WORM.

the rate of $3\frac{1}{2}$ miles per hour on rails, and from 1 to $1\frac{1}{2}$ tons on ordinary level roads.

Continuous Transport of Materials.—The continuous transport of materials is accomplished by conveyors, which may be classified as screw, scraper, band, vibrating and bucket conveyors.

The screw or worm conveyor consists of a trough containing a rotating screw by which the material is

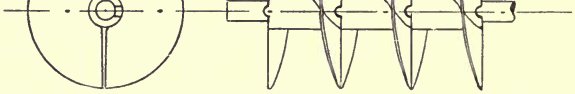


FIG. 61.—CAST-IRON WORM IN SECTIONS.

pushed along the trough. The lid of the trough is left loose so that in case of choking the lid lifts and the screw is not damaged. The material is delivered through an opening at the bottom of the trough near the delivery end. A certain amount of mixing takes place in such conveyors, and in some instances this feature is very valuable. In the paddle type of

worm (Fig. 60) the helix is formed by bolting blades of suitable section to the driving shaft. Cast-iron worms are made in sections (Fig. 61), which are threaded and fixed on the central shaft to form a continuous helix. Wrought-iron or mild-steel worms are made in several ways ; in the most recent forms

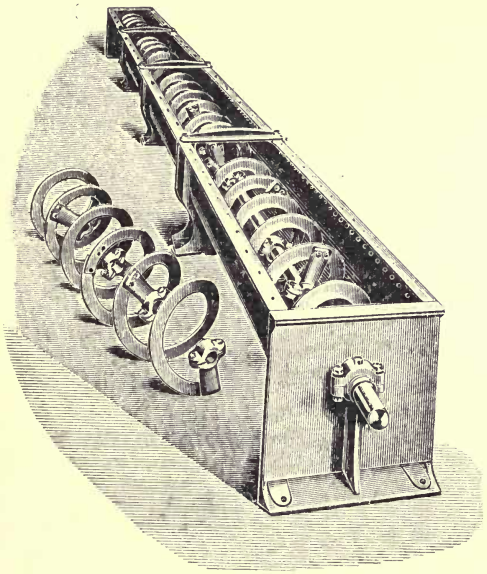


FIG. 62.—SPIRAL RIBBON CONVEYOR.

the thread of the worm is rolled from a flat strip of metal into a spiral form, and fixed in a groove cut in the central shaft. In the ribbon or spiral conveyor (Fig. 62) the worm is supported at a few points on the shaft as shown.

These worms rotate in troughs of wood or metal, with a clearance of from $\frac{1}{8}$ to $\frac{1}{4}$ in. The distance apart of the bearings depends on the stiffness of the

worm, and varies from 8 ft. for 4-in. worms to 12 ft. for 12-in. or larger worms. A total length of 100 ft. is usually considered as the practical limit on account of the torsional stresses in the shaft. The pitch of such worms varies from one-third of the diameter for heavy materials to the diameter for light materials, but for most materials a pitch equal to half the diameter of the worm gives satisfactory results.

The peripheral speed of worm conveyors depends largely on the character of the material, and varies, in good practice, from 150 for small to 300 ft. per minute for large worms; approximately, the number of revolutions per minute $= \frac{300}{\sqrt{d}}$, where d is the diameter of the worm in inches. The approximate capacity of continuous worms in cubic feet per hour $= 18\frac{1}{2}(d - 2\frac{1}{4})^2$. In the case of paddle or ribbon worms this figure should be reduced by 20%.

Gritty materials and substances which cake together are not suitable for transport by means of worm conveyors. With suitable materials the power required to drive worm conveyors is given approximately by the formula—

$$\text{H.P.} = \frac{\text{AWL}\mu}{33{,}000}$$

where W is the weight of the material conveyed per minute in lbs., L is the length of the trough in feet, μ is the coefficient of internal friction of the material, and A is a factor depending on the efficiency of the worm, and is usually about 2·5. The value of μ is given by the following table :—

COEFFICIENTS OF INTERNAL FRICTION.

Finely-ground coal (98% through 100-mesh sieve)	·29

Anthracite (·1 to 2-in. cubes) ..	·50
Wheat	·53
Sand or crushed ore	·67
Bituminous coal (·1 to 2-in. cubes) ..	·70
Ashes or soft ore	·84

A form of worm conveyor which is very convenient in some situations consists of a rotating tube provided with an internal spiral. Such conveyors take more power to drive and are somewhat limited in range of capacity. The best pitch for the spiral is about two-fifths of the diameter of the tube, and the peripheral speed is given by the formula for the ordinary worm conveyor (R.P.M. $= \frac{300}{\sqrt{d}}$).

Scraper Conveyors.

A typical scraper conveyor consists of a trough along which the material is pushed by means

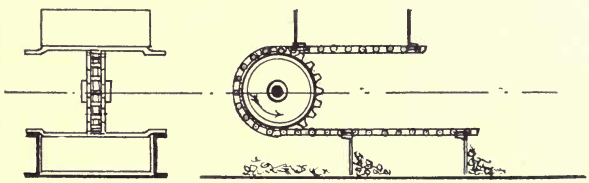


FIG. 63.—SCRAPER CONVEYOR.

of scrapers attached to an endless chain. At each end of the chain a terminal pulley is provided to drive or guide the chain, and guiding strips are fixed at the sides or in the middle of the trough over which bars or rollers pass to maintain the scrapers out of contact with the bottom and sides of the trough. Scraper conveyors, like worm conveyors, are unsuitable for hard and gritty materials. A simple form is shown in Fig. 63, from

which the arrangement of driving chain and guide plates is readily seen.

In some designs a central guide is used, in others the links of the chain form the scrapers, and again in others the sides of the trough are rendered unnecessary by the provision of sides to the scrapers.

A variety of scraper conveyor which is very useful in chemical factories, especially where sludge is transported in channels of too small an inclination to prevent settlement, consists of a rope carrying discs or pistons of metal or wood which push the material along the V or U-shaped trough.

The speed of scraper conveyors varies from 50 to 150 ft. per minute, and the power required is readily estimated by means of the formula—

$$\text{H.P.} = \frac{\text{AW.L.}\mu + b.w.s.}{33{,}000}$$

where W is the weight of material transported per minute, L is the length of the conveyor, μ is the coefficient of internal friction of the material, A is a factor (usually about 1·25), b is a frictional factor (·01), w is the weight of the chain and scrapers, and s is the speed of the scrapers in feet per minute.

Band Conveyors.

Band conveyors consist of endless belts to carry the material to be transported, which run over terminal pulleys and are supported at intervals by guide pulleys.

Although the band conveyor in its original form was only suitable for light materials, it is now largely used for heavy materials as well.

There are three types of band conveyor : (1) light band conveyors in which the band remains with a flat surface ; (2) heavy band conveyors in which the band when carrying the material is kept hollowed by suitable guide pulleys ; (3) metal band conveyors.

The bands of light band conveyors are made of cotton or other cloth covered or treated with rubber, guttapercha or balata. The supporting or guide rollers are generally about 6 ins. diameter, and are spaced at distances of 6 ft. on the loaded and at

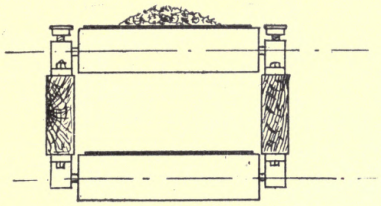


FIG. 64.—BAND CONVEYOR (SIMPLE SUPPORTING ROLLERS).

12 ft. on the slack or unloaded side. The bearings of these rollers are generally carried by a pair of steel or timber joists, as shown in Fig. 64. When delivery takes place at a fixed position a simple screw adjustment for tightening the belt is sufficient,

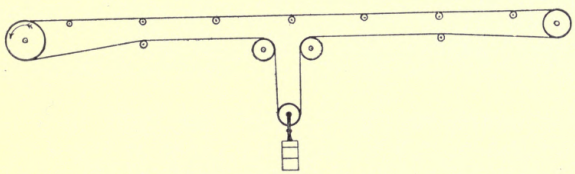


FIG. 65.—BAND CONVEYOR (TIGHTENING ARRANGEMENT).

but in other cases a weighted pulley round which the empty side of the belt passes, is necessary to give the requisite tension (Fig. 65).

The driving pulley should always be placed to make the loaded side the tight side of the belt.

The material may be discharged from the belt at

the driving pulley, but for discharge at an intermediate point a throw-off carriage is required (Fig. 66). The band rises to the upper pulley of this carriage and changes its direction suddenly by passing round the lower pulley, while the material

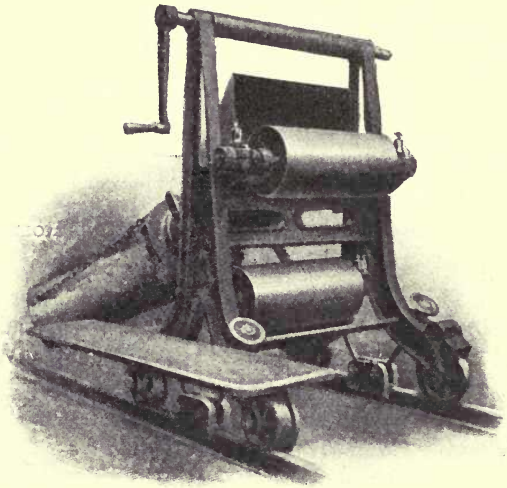


FIG. 66.—THROW-OFF CARRIAGE.

by its inertia travels forward and falls into the hopper shown and through the shoot at the side.

The material must be delivered on to the middle half of the band at a horizontal velocity approaching that of the band. This is readily accomplished by the use of a shoot inclined at an angle of from 40 to 45 degs. When working such bands at their full capacity a pair of inclined rollers are sometimes provided to hollow the band at the point of charging, and sometimes such rollers are fitted at intervals when spreading of the material is feared.

The speed of band conveyors for grain and light material varies from 400 to 600 ft. per minute, and the capacity of bands of over 9 ins. width is given in tons per hour when running at 500 ft. per minute by the formula—

$$C = \left(\frac{b}{2} - 2\right)^2$$

where b is the width of the band in inches.

In band conveyors for heavy materials the edges of the belt are turned up to form a trough by means

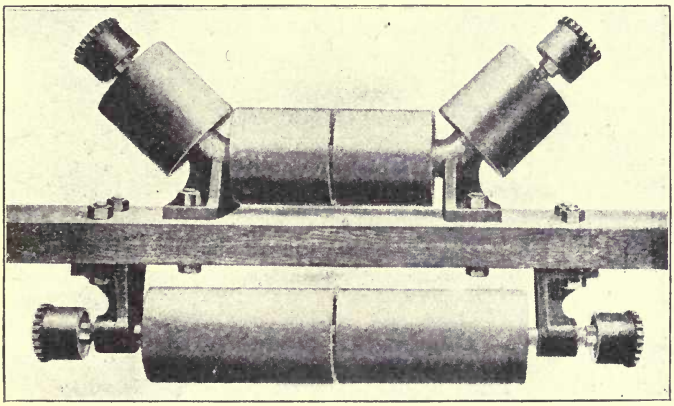


FIG. 67.—SUPPORTING GUIDE ROLLERS.

of supporting guide rollers; the belts are much stronger and the fittings more substantial. The guide rollers and brackets for supporting them are usually made as shown in Fig. 67. The rollers are of equal diameter, the axes of the outer rollers being inclined to produce the troughing. The best inclination to the horizontal of these "troughing idlers" is probably 20 degs. for general work, although shallower and deeper troughing is common. In addition

to troughing rollers, small guide rollers may be used at long intervals where any tendency for the band to move sidewise needs checking. The best bands consist of several layers of stout canvas treated with and covered with rubber. The thickness of the rubber covering is made greatest where wear and tear is most severe, and the upper surface is often provided in the middle with a thickness of solid rubber of over $\frac{3}{4}$ in. tapering to the edges to about $\frac{3}{8}$ in. thick. The life of the bands is much affected by chemical influences and moisture ; every care should be taken to prevent the exposure of the canvas, either by wear or by surface cracking of the rubber. Canvas belts treated with a mixture of balata and guttapercha are used for the lighter kinds of work, and woven wire belts for immersion in liquids.

The speed of the belts of heavy band conveyors varies from 150 ft. to 400 ft. per minute, and depends mainly on the size of the material. For general work a speed of 250 ft. per minute is satisfactory, but with finely divided material a higher speed may be used with increased economy.

The driving pulleys should have a diameter not less than forty times the thickness of the belt at its thickest part, and in all cases greater than the width of the belt used. The faces of the driving pulleys should be slightly rounded and from 1 to 2 ins. wider than the belt.

The loading of band conveyors requires careful treatment, and the shoot should be curved near the band and provided with an adjustment so that the discharge from the shoot is only slightly inclined to the horizontal and the velocity of the material is as nearly as possible equal to that of the band. Neglect of this precaution with heavy materials produces excessive wear. This shoot should also be provided with side boards to prevent the material spreading. The load must not be delivered on to the band over

a set of supporting rollers, but at some intermediate point, and the rate of feed should be regulated. Each similar detail of design and operation to avoid wear increases the life of the bands.

The discharge from the bands may be made by means of a throw-off carriage, which, for filling bins, is often made to move automatically backwards and forwards on its track.

Band conveyors can be used for elevating, provided that the inclination is not more than 20 degs. With some materials this angle may be increased to 25 degs.

The capacity of heavy band conveyors is approximately given by the formula—

$$C = \frac{w.s.b.^2}{72{,}000},$$

where C is the capacity in tons per hour ; w is the weight of the material in lbs. per cubic foot ; s is the speed of the belt in feet per minute, and b is the width of the belt in inches. The capacity can be more closely estimated by reference to a scale drawing showing the character of the loading.

The power required to drive band conveyors varies enormously with the workmanship and design of the installation.

Ball bearings and other devices for reducing friction are coming into favour on account of the increased efficiency obtained. A useful estimate of the power required is given by—

$$\text{H.P.} = \frac{(\text{W.L.}e + f.w.s. + \text{W.}h)}{33{,}000},$$

where W is the weight of material in lbs. conveyed per minute ; L is the length of the conveyor in feet, and e is a friction coefficient, approximately ·08 ; w is the weight in lbs. of the moving parts of the conveyor at the speed of the belt (the equivalent weights of

the pulleys and guide rollers should be calculated); s is the speed of the belt in feet per minute, and f is a frictional coefficient, approximately ·03; h is the height in feet through which the material is lifted, which, of course, may be negative.

Throw-off carriages absorb power in proportion to their size. A rough approximation for belts over 10 ins. wide is given by—

$$\text{H.P.} = \frac{b}{8} - 1.$$

Belt conveyors with fabric belts require little power, and the wear and tear is small, but they are expensive in first cost. The load cannot be withdrawn in a simple way, and the number of small bearings to be attended to and kept in repair is great.

Metal Band Conveyors.

Although continuous steel bands, similar to those used as main driving bands, have not been used for conveyors, there is no doubt that before long such bands will come into effective use. Ordinary metal band conveyors consist of a series of overlapping plates which are jointed together or carried on chains. Such conveyors must be driven from the delivery end at from 60 to 120 ft. per minute; they form excellent sort ng tables, but, being complicated in construction, they need much attention to keep them in good order.

Vibrating Trough Conveyor.

This conveyor consists of a trough which is supported on flat springs, from above or below, inclined 15 degs. to the vertical, and vibrated by means of a cam or crank. The main construction of a simple form is shown in Fig. 68. On the forward stroke of the crank the material is impelled forward

by the trough rising, and on the backward stroke it continues its motion and the trough falls to its original position. The stroke of the crank or cam is about $\frac{7}{8}$ in., and the number of revolutions per minute 300 to 370, the material moving along the trough at a speed of from 40 to 70 ft. per minute. The connection of the driving connecting rod to the trough is made through a spring, so that the stroke of the trough is a little longer that the stroke of the cam or crank and the action is more gentle. By arranging two troughs in series and driving them in opposite phase a well-balanced arrangement taking less power is obtained. Slides are arranged

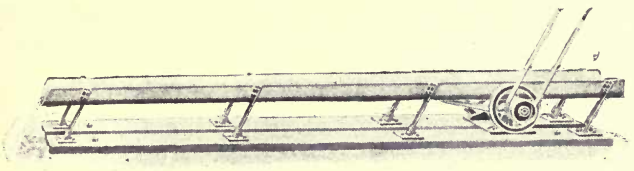


FIG. 68.—VIBRATING TROUGH CONVEYOR.

at the bottom of the trough for the withdrawal of the material at any point.

With troughs 4 ins. deep the capacity is about $\frac{1}{2}$ ton of coal per inch of width per hour. The power required is about twice that required for heavy brand conveyors.

The great advantage of this conveyor is its simplicity, small number of working parts, and the fact that it will work horizontally or at slight inclination in either direction.

A modification of this conveyor consists in replacing the springs by rollers which move in a shaped path. Such conveyors are used with greater efficiency for large heavy materials, occupy less space and are easily portable. The number of

revolutions or vibrations is considerably reduced and the stroke lengthened.

Elevators.

The ordinary elevator consists of one or more endless bands or chains carrying buckets to hold the material and supported above and below on suitable wheels. The upper wheel is usually arranged for driving, so that the loaded side of the conveyor is the tight side. The lower wheel works in a well, which is adapted to receive the material to be elevated. In all cases the elevator should be enclosed in a suitable casing, which may be of wood for light and sheet metal for heavy materials. For light powders bands of leather or of cotton or hemp impregnated with rubber, balata, guttapercha, etc., are used, to which the buckets are rivetted. Such elevators can be run at high speeds, viz., 250 to 600 ft. per minute, so that, on the buckets passing over the upper wheel, the material is thrown some distance away from the wheel. On this account the elevator can be placed nearly vertical. The pulleys used to carry the belts are always round-faced, and their diameter, to give easy delivery, at speeds from 250 to 500 ft. per minute is given by the formula—

$$d = \cdot 17\, s - 30$$

where d is the diameter in inches, and s is the speed of the band in feet per minute.

For heavy materials the buckets are carried on chains (Fig. 69 and Fig. 70), and, on account of their lower speed, 50 to 200 ft. per minute, the elevator must be placed at an angle in order that the delivery at the upper terminal may be readily accomplished. The most convenient angle is 60 degs. The upper pulley or sprocket wheel must be just above the edge of the delivery spout, but the determination

of the path of the material is not difficult. When the buckets are close together care must be taken that the underside of the preceding bucket does not inferfere with the delivery.

Tightening devices, one of which is seen in Fig. 70, must be provided at the lower or upper terminal. Such devices at the top interfere with the drive and

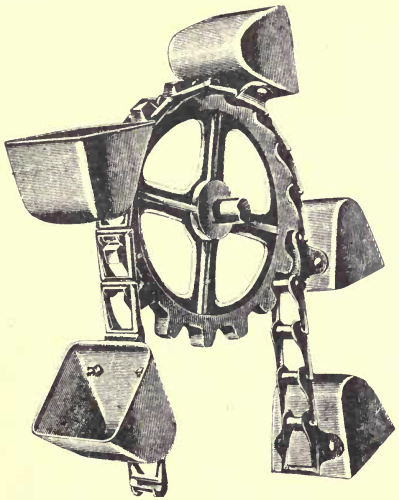


FIG. 69.—BUCKETS, CHAIN AND SPROCKET WHEEL.

at the bottom with the feed. When elevating material which is heavy or cakes, it is best to put the tightening gear at the top, or make the well move with the lower wheel.

With most materials it is common practice to allow the buckets to scrape up the material from the well, and in such cases the mouth of the feeding hopper should not be above the centre line of the lower wheel. It is always desirable to provide feeding devices, so that the material falls directly

into the buckets. Where the buckets are continuous, a form of conveyor giving the greatest

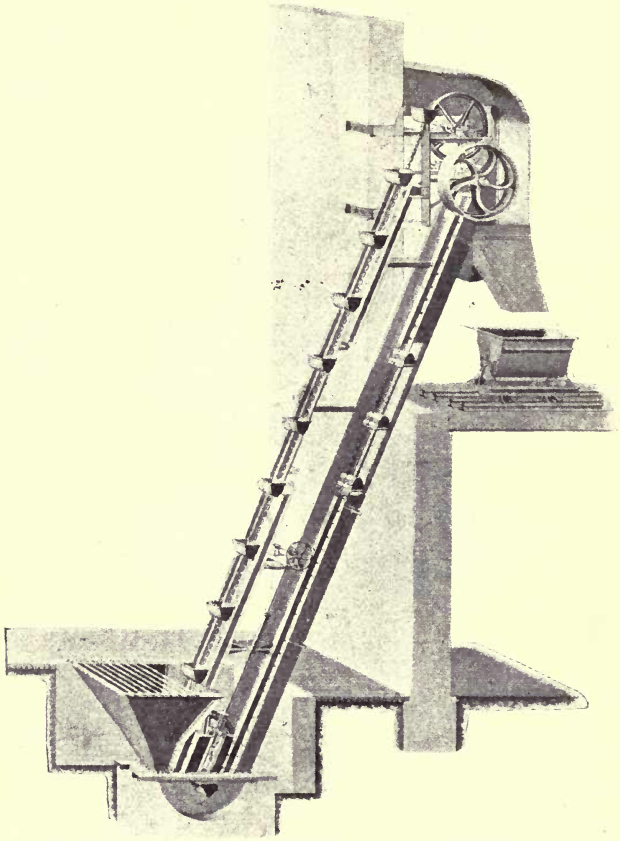


FIG. 70.—ELEVATOR FOR HEAVY MATERIALS.

efficiency, this method of feeding is simple. A shaking hopper or hopper base, which can be

adjusted by altering its inclination or its stroke, is the simplest device for feeding, but worm and finger feeds are sometimes used.

With heavy materials, on account of the inclination of the elevator, each bucket is provided with a " skidder bar " which slides on guide plates fixed to the elevator casing. Single chains (Fig. 69) are, in practice, superior to double chains from all points of view.

The size and shape of the buckets must be considered for every material. For light powders shallow buckets with wide angled sides should be chosen, so that emptying is complete before the bucket gets into an unfavourable position. For heavy materials deep buckets with only slightly inclined sides may be used.

Where heavy material is to be elevated vertically, a double chain elevator with the buckets between the chains may be adopted. In this arrangement guide wheels may be fitted under the upper terminal to direct the buckets inwards and give a clean delivery of the material to the delivery shoot.

BRADBURY, AGNEW & CO. LD., PRINTERS, LONDON AND TONBRIDGE.

UNIVERSITY OF CALIFORNIA LIBRARY

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

AUG 5 1916

JUL 31 1920

MAY 14 1921

30m-1,'15

YB 15491

TP155
H5

321771

UNIVERSITY OF CALIFORNIA LIBRARY